Sriyaraj, Kanyawat, 2006.
Local air quality management and health impacts of air pollution in Thailand.
Available from Middlesex University's Research Repository.

LOCAL AIR QUALITY MANAGEMENT AND HEALTH IMPACTS OF AIR POLLUTION IN THAILAND

KANYAWAT SRIYARAJ

Urban Pollution Research Centre
School of Health and Social Sciences
Middlesex University

Submitted in partial fulfilment of the requirements of Middlesex University for the degree of Doctor of Philosophy

2006

ABSTRACT

Air quality in urban areas of Chiang Mai Province, Thailand has seriously deteriorated as a consequence of population growth and urbanization and due to a lack of effective air quality management (AQM). As a result, respiratory diseases among Chiang Mai residents have increased in these affected areas. The health status and experiences of air pollution of both children and adults in Chiang Mai was assessed and improvements recommended to the developing AQM scheme. Air quality modelling, using ADMS-Urban was used to identify probable air polluted and control sites for further study. The polluted sites were found to be located along major roads in the city. However, ADMS-Urban was unable to predict air pollutant concentrations accurately because it could not cope with the very low wind speeds and complex topography of Chiang Mai. As a result, the utility of other air pollution modelling programmes should be investigated. The results of a questionnaire survey conducted with adults showed that urban respondents had a higher percentage of respiratory diseases than suburban respondents. However, later investigations were unable to establish a statistical linkage between air pollution concentrations and respiratory diseases. An ISAAC study was conducted among children attending schools located in the selected sites to assess the potential impacts of air pollution on health. The results showed that the prevalence of asthma was similar in all of the schools (approximately 5%) but that the prevalence of rhinitis (24.3% vs. 15.7%) and atopic dermatitis (12.5% vs. 7.2%) was higher in the urban schools which were considered to be more polluted. Logistic regression analysis identified other factors which may be involved in addition to pollution, including some components of the diet and contact with animals. In order to investigate the adequacy of the AQM system in Thailand, a comparative study was conducted between Hong Kong and Thailand. Both countries were investigated with respect to conformance to Good Urban Governance. The comparison showed that there are significant differences between the two countries and the AQM system in Hong Kong was more highly developed. For example, in contrast to the system in Hong Kong, it was found that there was insufficient involvement of the population in the development and implementation of AQM systems in Thailand. In order to better understand the reasons why the AQM system in Thailand is poor at both the provincial and local levels in Chiang Mai, prioritisation of AQM was assessed for major national environmental policies and plans; at the provincial level, fund allocations to development projects were reviewed; and at the sub-district level; a questionnaire survey was conducted among local government officials. It was concluded that AQM was not given sufficiently high priority in national plans and was generally ineffective and that, due to the non-specific nature

of guidelines and frameworks in these plans, it was difficult for government organizations at the lower levels to establish AQM action plans for effective implementation. A range of appropriate measures to improve air quality in Chiang Mai were recommended. These included a more effective management of air pollution, an identified need for training and major changes in the transport system in the city.

ACKNOWLEDGEMENTS

I would like to thank Prof. Brian Shutes, for giving me the opportunity to study at *Middlesex University* and for his advice and support for my research. I would also like to express my sincere thanks to Prof. Nick Priest, for his academic advice, support and understanding. Special thanks are also due to Asst. Prof. Phongtape Wiwatanadate, of *Chiang Mai University, Thailand* who helped with my supervision. Finally, there are many *Middlesex University* staff, behind the scenes that have helped, including: Dr. David Jarrett; Dr. Huw Jones; Prof. Mike Revitt; Prof. Ron Hamilton; Ms. Rhona Steven; Ms. Helen Crabbe; Ms. Margaret Davis; Dr. Hemda Garelick; and Mr. Paul Kershaw, Ms. Mary Constantinides, Ms. Chris Constantinou, and Ms. Lily Lim.

I am deeply grateful to Mr. Ross Sneddon (Cawthron Institute, Nelson, New Zealand) for his editorial assistance and kind support while I was staying in Nelson.

I am very grateful for assistance from the following officials of *Chiang Mai Office of Public Works and Town and Country Planning, CMOPT, Thailand*: Ms. Pochanie Kajornpredanon, Head of CMOPT; Mr. Pichat Ouiyanukoon; Mr. Satian Debough; Mr. Awirut Bunprasith; Mr. Surapol Sarttapat; Ms. Ampaporn Keawgate and Ms. Tiamrat Insee; Ms. Peungpit Ngamsai; Ms. Sunanta Jainual; Ms. Khakhanang Sonthiplengsri; Ms. Pawantee Junping; Ms. Noppawan Thainjun; Mr. Apisak Kumthong. I also very much appreciate the support from Assoc. Prof. Supot Wudhikarn, Dean of *Faculty of Medicine, Chiang Mai University,* and his following colleagues; Assoc. Prof. Muthita Trakultivakorn; Ms. Kitirat Mahasu and Ms. Siriboon Yavichai. My gratitude to Assoc. Prof. Ratana Panpanich, *Head, Department of Community Medicine, and* Mr. Thurdkiat Makasuk and staff including Ms. Viranlapach Subhinnapongse and other interviwers. For PM_{10} monitoring, I am indebted to Dr. Somporn Chantara and Miss Walaya Sangchan, *Department of Chemistry, Faculty of Science*. My gratitude to Assoc. Prof. Suwasa Kantawanichkul, Asst. Prof. Kajornsak Sopajaree, and Dr. Petch Pengchai, from *Department of Environmental Engineering*. My sincere thanks to Mr. Pathom Puapansakul and his family, and Kangsadal Resort, Chiang Mai.

I would also like to especially thank the Directors and staff of the following schools in Chiang Mai; Ban Korntal School; Wat Saimoon School; Wat Sripotaram School; Tao Bunruang School; Ban San Pasak School; Ban Donpin School, and my gratitude to the students and their parents for co-operation in the health survey. I would also like to thank the following organisations for providing useful data: *Chiang Mai Office of Meteorology; Department of Geography, Chiang Mai University; Chiang Mai Provincial Office; Chiang Mai Municipality* especially Mr. Sanae Chandrapipat, Mr. Wisan Kamloy and Mr. Panyapol Mongkolchareon; *Environmental Office (Region 1)* (Mr. Apiwat Kunarak and Ms. Suwaree Singpetch); *Pong Yang Sub-district Administration Office* (particularly the Chief Executive and his deputy as well as Ms. Thitirat Intaping). My special thanks to the Pollution Control Department (PCD), Bangkok, Dr. Supat Wangwongwatana, Deputy Director General; Ms. Mingquan Wichayarangsaridh, Director of *Air Quality and Noise Management Bureau*, and her staff - Mr. Panya Warapetcharayut, Mr. Aunnop Rungraksathum, Mr. Montri Chutichaisakda.

I would like to express my sincere thanks and considerable appreciation to officials at the *Hong Kong Environmental Protection Department* (EPD) who facilitated my visit in November 2004; Dr. Peter Louie and his staff, and his colleagues: Dr. Christopher Fung and Mr. Lau Hin Chung; Mr. P. C. Choi and his staff; Mr. Gordon Leung; Mr. David Jor; Mr. K. P. Ching; Mr. Tsui Wing-Sing. Special thanks to Dr. Patricia Gilmour and colleagues from the *Cambridge Environmental Research Consultants (CERC), UK* for air modelling advice. I am indebted to Mr. Khemmawit Sriyaraj, my brother for computer graphic effort. A special thanks to Ms. Jaree Jaimook for sketching school perspective views; and Mr. Thanakorn Chaijinda for permission to use his painting. My gratitude to Mr. Paitoon Sungtaim and Ms. Supisra Sungtaim for an internet access. My special thanks to Mr. Iain Watson. I am very grateful for support and encouragement from my parents. The project was part-funded by the European Commission (EC) – Asia Urbs Programme.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES AND BOXES

LIST OF ACRONYMS

AD	Aerodynamic Diameter
ADB	Asian Development Bank
ADMS-Urban	Atmospheric Dispersion Modelling System (Urban version)
ALA	American Lung Association
ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
APCO	Air Pollution Control Ordinance
API	Air Pollution Index
APMA	Air Pollution in Megacities of Asia Project
AQM	Air Quality Management
AQO	Air Quality Objectives
ATS	American Thoracic Society
BBC	British Broadcasting Corporation
BMR	Bangkok Metropolitan Region
Btu	British thermal unit
CALINE4	California Line Source Dispersion Model Version 4
CEO	Chief Executive Officer
CERC	Cambridge Environmental Research Consultants Ltd., UK
CLP	China Light & Power Hong Kong Ltd.
CM	City Municipality, Thailand
CMM	Chiang Mai Municipality
CMOPT	Chiang Mai Office of Public Works and Town and Country Planning
CMU	Chiang Mai University
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Diseases
CRANC	Committee for Resolving Dust, Air and Noise Pollution in Chiang Mai
CRP	Community Relations Programme
DEDP	Department of Energy Development and Promotion, Thailand
DEFRA	Department for Environment, Food and Rural Affairs, UK
DEQP	Department of Environmental Quality Promotion, Thailand
DETR	Department of the Environment, Transport and the Regions, UK
DfT	Department for Transport, UK
DIW	Department of Industrial Works, Thailand
DoH	Department of Health, UK
DMRB	Design Manual for Roads and Bridges (UK)
DPT	Department of Public Works and Town and Country Planning, Thailand
DOAE	Department of Agricultural Extension
DOLA	Department of Local Administration, Thailand
DOPA	Department of Provincial Administration, Thailand
CAI-Asia	Clean Air Initiative for Asian Cities
CEO	Chief Executive Officer
CMB	Chiang Mai Bus
CP	Cleaner Production
CT	Cleaner Technology
CRANC	Committee for Resolving Dust, Air, and Noise Pollution in Chiang Mai
CUP	Comprehensive Urban Plan
DIESEL	Developing Integrated Emission Strategies for Existing Land Transport Programme
EC	European Commission
EE	Environmental Education
EGAT	Electricity Generating Authority of Thailand
EIA	Environmental Impact Assessment
EM	Environmental Management
EMF	Environmental Management Framework
EMIT	Atmospheric Emissions Inventory Toolkit

EO1	Environment Office (Region 1), Chiang Mai
EPD	Environmental Protection Department, Hong Kong SAR
EQMP	Environmental Quality Management Plan
ERC	Environmental Resource Center
ERS	European Respiratory Society
ETS	Environmental Tobacco Smoke
EU	European Union
FC	Fluorocarbon
FCO	Foreign and Commonwealth Office, UK
FEV_1	Forced Expiratory Volume in 1 Second
FDM	Fugitive Dust Model
FGV	Flue Gas Desulfurisation
FRV	Functional Residual Volume
FVC	Forced Vital Capacity
GINA	Global Initiative for Asthma
GIS	Geographic Information System
GMP	Government Management Plan
GPS	Geographic Positioning System
GUG	Good Urban Governance
HC	Hydrocarbon
HEC	Hong Kong Electric Co. Ltd.
HEI	Health Effects Institute, Boston, USA
HK SAR	Hong Kong Special Administrative Region
H_2S	Hydrogen sulphide
IAQ	Indoor Air Quality
IgE	Immunoglobulin E (antibodies)
ICT	Information and Communication Technology
IPSR	Institute for Population and Social Research, Thailand
ISAAC	International Study of Asthma and Allergies in Childhood
ISC	Industrial Source Complex
ISCST3	Industrial Source Complex Dispersion Model Short Term Version 3
ISO	International Organization for Standardization
JBIC	Japan Bank of International Cooperation
JICA	Japan International Cooperation Agency
KS	Kanyawat Sriyaraj
LAPC	Local Air Pollution Control
LAPPC	Local Air Pollution Prevention and Control
LAQM	Local Air Quality Management
LBB	London Borough of Barnet, UK
LLN	Lower Limit for the Normal Range
LPG	Liquefied Petroleum Gas
LRI	Lower Respiratory Infection
MAAPE	Medical Aspects of Air Pollution Episodes
MAQHUE	Managing Air Quality and Health in the Urban Environment project
MARC	Monitoring and Assessment Research Centre, UK
MDE	Maryland Department of Environment, USA
Models-3/CMAQ	Models-3 Community Multi-scale Air Quality
MONRE	Ministry of Natural Resources and Environment, Thailand
MOPH	Ministry of Public Health, Thailand
MOST	Ministry of Science and Technology, Thailand
MOSTE	Ministry of Science, Technology and Environment, Thailand
MOU	Memorandum of Understanding
MTP	Master Town Plan
MU	Middlesex University, UK
NAAQA	National Ambient Air Quality Standards, USA
NAEI	National Atmospheric Emissions Inventory, UK

NCAR	National Centre for Atmospheric Research, Pennsylvania State University
NEQA	Enhancement and Conservation of National Environment Quality Act (1992)
NESDB	National Economic and Social Development Board
NESDP	National Economic and Social Development Plan
NGO	Non-governmental Organizations
NHS	National Health Service, UK
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NMC	Northern Meteorological Centre, Chiang Mai
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
NREM	Natural Resources and Environmental Management
O_3	Ozone
OCMRT	Office of the Commission for the Management of Road Traffic, Thailand
OLPO	Ozone Layer Protection Ordinance
ONEP	Office of Natural Resources and Environment Policy and Planning, Thailand
OPS	Office of the Permanent Secretary of Natural Resources and Environment, Thailand
OTOP	One Tambon (sub-district) One Product
Pb	Lead
PAEO	Provincial Agricultural Extension Office, Chiang Mai
PAO	Provincial Administration Office, Thailand
PAQLQ	Pediatric Asthma Quality of Life Questionnaire
PCD	Pollution Control Department, Thailand
PEF	Peak Expiratory Flow
PEO	Provincial Education Office, Chiang Mai
PHO	Provincial Health Office, Chiang Mai
PIO	Provincial Industry Office, Chiang Mai
PM_{10}	Particulate matter with less than 10 μm (micron) in aerodynamic diameter
PLTO	Chiang Mai Provincial Land Transport Office
PONRE	Provincial Office of Natural Resources and Environment
PPMP	Pollution Prevention and Mitigation Policy
PRD	Pearl River Delta
PRD3	Public Relations Department Region 3, Chiang Mai
PRDEZ	Pearl River Delta Economic Zone
PRQLQ	Pediatric Rhino-conjunctivitis Quality of Life Questionnaire
PWO	Public Warehouse Organization, Thailand
QA	Quality Assurance
QBG	Queen Sirikit Botanic Garden, Chiang Mai
QC	Quality Control
QoL	Quality of Life
RSP	Respirable Suspended Particulates (normally used by EPD, Hong Kong SAR)
RTP	Royal Thai Police
SAO	Sub-district Administration Organization
SC	Sub-district Council, Thailand
SEPA	Student Environmental Protection Ambassador
SO_2	Sulphur dioxide
SM	Sub-district Municipality
SME	Small- and Medium-sized Enterprise
SPM	Suspended Particulate Matter
SPSS	Statistic Programme for Social Science
TPCA	Town and Country Planning Act
TEI	Thailand Environment Institute
THB	Thai Baht
TLC	Total Lung Capacity
TMD	Thai Meteorological Department, Thailand
TNEC	Thailand Network of Eco-efficiency and Cleaner Production
TSP	Total Suspended Particle
TUGI	The Urban Governance Initiative

UAM-V	Urban Airshed Model – variable grid
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UN-HABITAT	United Nations Human Settlements Programme
UK	United Kingdom
URI	Upper Respiratory Infection
USA	United States of America
US AEP	United States Asia Environmental Partnership
US EPA	United States Environmental Protection Agency
US NAAQS	United States National Ambient Air Quality Standards
UTM	Universal Transverse Mercator
UV	Ultraviolet
VOC	Volatile Organic Compound
WB	World Bank
WHO	World Health Organisation
WMO	World Meteorological Organisation
WRI	World Resources Institute

CHAPTER 1

RESEARCH BACKGROUND AND LITERATURE REVIEW

1.1 Research Background

This PhD research programme was originally developed as an integral part of the project *Managing Air Quality and Health in the Urban Environment* (MAQHUE), under the Asia Urbs programme, funded by the European Commission (EC). The programme focuses mainly on the transfer of knowledge between European and Asian countries. It aims to transfer practical techniques and implement sustainable strategies for the socio-economic development of Asian countries through partnerships among local governments, resulting in an improvement to the urban environment and the quality of life (Europa, 2004). The MAQHUE project aimed to establish and build links between local communities, local authorities and universities in the United Kingdom, Spain and Thailand. The project was intended to deliver appropriate techniques to manage local air quality in the urban environments concerned, develop respiratory health research and information programmes, methods and tools of assessment and analysis, and ultimately share experiences and disseminate techniques regarding local air quality management. The project consortium comprised: London Borough of Barnet (LBB) (Project Leader/Co-ordinator); Urban Pollution Research Centre, Middlesex University (MU), UK; Generalitat de Catalunya, Barcelona, Spain (Partner); Chiang Mai Provincial Administration Organisation (PAO) (Partner), Chiang Mai University (CMU), Environmental Office Region 1 (EO1); Chiang Mai Office of Public Works and Town and Country Planning, (CMOPT), Thailand. The two year project started in 2002, the project deliverables in Chiang Mai included the establishment of air pollution stakeholders, air quality modelling using an urban version of the Atmospheric Dispersion Modelling System (ADMS-Urban), and a quality of life survey using a questionnaire previously employed by LBB. The general review of air quality status in Thailand and the UK, the use of ADMS-Urban and the quality of life survey were then subsumed within the current research project. However, subsequently the MAQHUE project was terminated due to unforeseen circumstances and support for the PhD from this project ceased. Consequently, the current thesis contains required aspects developed for the MAQHUE project, plus new investigations developed subsequently. In addition, the London Borough of Barnet was originally selected to serve as an example of local air quality management (LAQM) for Chiang Mai but this is not the most appropriate and was later changed to the Environmental Protection Department (EPD), Hong Kong Special Administration Region (HK SAR). The EPD is a national environmental regulator, hence its air quality management approaches can be compared directly with those of the Thai Pollution Control Department (PCD), which has similar roles. The responsibilities of HK EPD and Thai PCD are outlined later in detail. Due to more advanced aspects of air pollution control and management, HK SAR can be used as an Asian example for Thailand. Both HK EPD and Thai PCD are also governmental members of the Clean Air Initiative for Asian Cities (CAI-Asia), which promotes and demonstrates innovative ways to improve the air quality of Asian cities through partnerships and experience sharing in air quality management (Clean Air Net, 2006). Through the link between MU and HK EPD, Dr. Peter Louie, Senior Environmental Protection Officer (Acting), Air Science Group, allowed the author to visit his department in November 2005 in order to learn about its air quality management activities.

1.2 Objectives of Research Programme

The objectives of the research undertaken for this thesis were as follows:

i) To describe the air pollution status of Chiang Mai and its surrounding provinces in Thailand;

ii) To compare air quality data for Chiang Mai with national air quality standards, and identify areas that are likely to be polluted (hot-spots) using the ADMS-Urban dispersion modelling system;

iii) To assess the health status and experiences of air pollution of residents in Chiang Mai using data from previously applied questionnaire(s) and surveys concerning child health;

iv) To compare current Air Quality Management (AQM) approaches in Thailand/Chiang Mai with those employed in Hong Kong Special Administrative Region (SAR);

v) To recommend improvements to the developing AQM scheme for Chiang Mai, including measures to raise public awareness of the potential health effects arising from air pollution and other environmental causes.

1.3 Research Approach Employed

The structure of this thesis and the work undertaken for it are outlined in Figure 1.1. This figure shows the logical sequence of the research, from initial air quality modelling in Chiang Mai, through various research components to recommendations for a sustainable

AQM system in Chiang Mai and the final consideration of possible future work. Within the structure of the thesis, a single chapter has been completed for each topic. Following the results of air quality modelling in Chiang Mai, the next chapters identify potential health effects that may be attributed to exposure to air pollution, both in adults and children. These sections are followed by chapters concerned with defining the current status of AQM in Thailand in general and Chiang Mai in particular and with comparing the Thai AQM systems with the more developed systems of a country with a similar climate – namely Hong Kong SAR. Finally, actions, which could be adopted by Thai authorities to implement an effective, sustainable AQM system for Chiang Mai, are recommended.

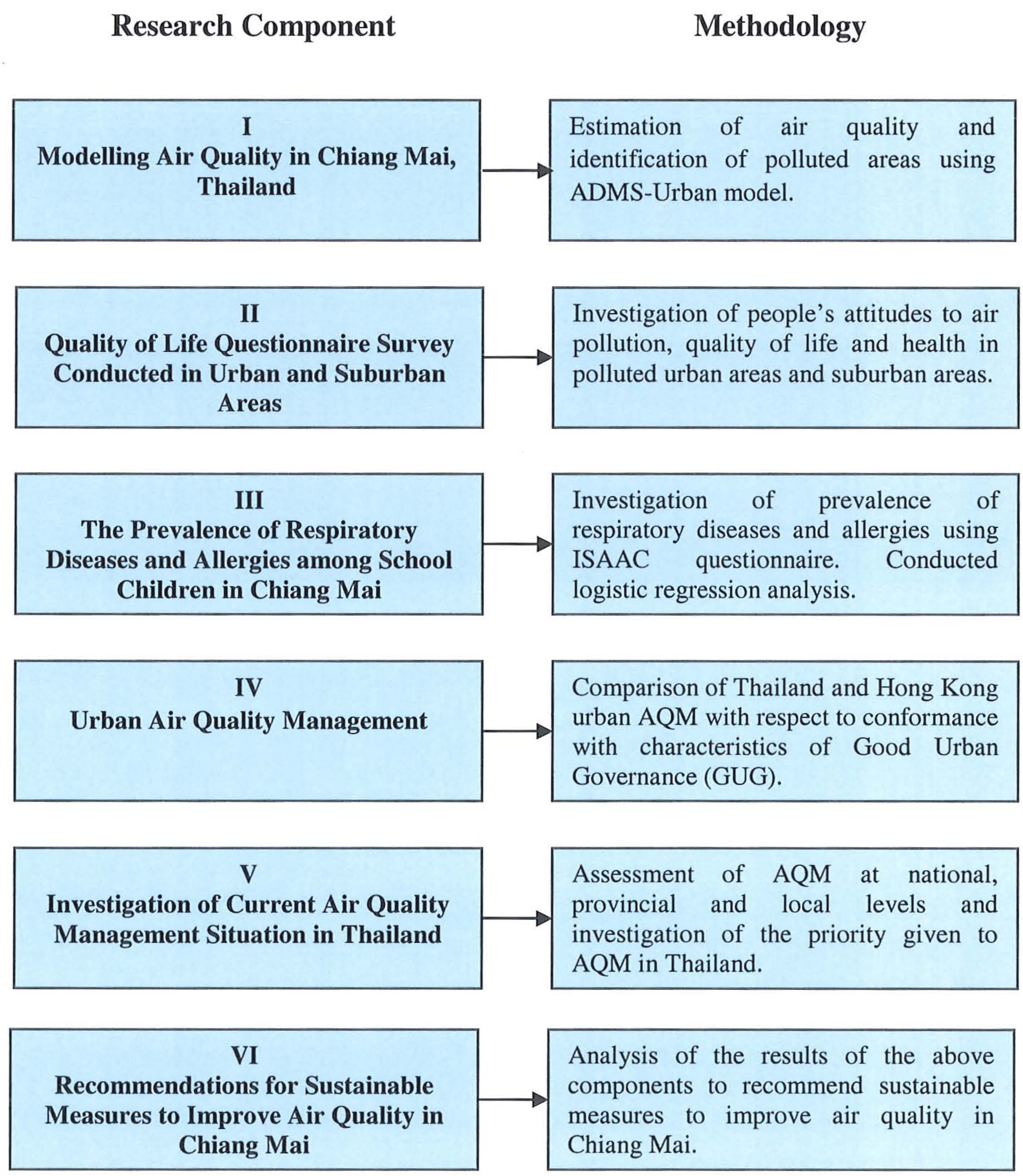


Figure 1.1 Chart illustrating major research components and methodology of the PhD research study titled 'Local Air Quality Management and Health Impacts in Thailand'

The ADMS-Urban software programme, developed by Cambridge Environmental Research Consultants (CERC), UK, was selected by a project manager of the MAQHUE project to use as a tool for air quality management and specifically to identify highly polluted areas in Chiang Mai. The selection of a British dispersion model is consistent with one of the principal aims of the Asia Urbs programme regarding technology transfer from Europe to Asian countries. However, it was found that the results of ADMS-Urban, when applied to Chiang Mai, fell short of expectations and did not match well with locally collected monitoring data. This is thought to be due to weather and topographic conditions in Chiang Mai (e.g. very low wind speed in winter, and complex mountainous topography). Nevertheless, the model did prove useful in terms of the identification of air pollution 'hot-spots' where the highest concentrations of air pollutants were predicted in its graphical output (pollution maps). This output was useful during site selection for both the quality of life questionnaire survey conducted in urban and suburban areas (Chapter 3) and the study of the prevalence of respiratory diseases and allergies among school children (Chapter 4).

As part of the MAQHUE project, in order to investigate people's attitudes to air pollution and its relationship to health and quality of life, a questionnaire survey of 2,000 Chiang Mai residents was conducted. At that time, this survey was led by Dr. Phongtape Wiwatanadate, Department of Community Medicine, Chiang Mai University. The UK partners (LBB and MU) supplied the questionnaire to Dr. Wiwatanadate in order to conduct a similar survey to one carried out in Barnet, UK. The questionnaire was translated into Thai (by the author) and some questions were modified (by Dr. Wiwatanadate) so as to be more suitable for Chiang Mai. The locations used for the survey were based on the results from the modelling component. The design and modification of the questionnaire were beyond the control of the author. Due to the non-distribution of funds by the Chiang Mai partner at that time, the funds for this survey were supplied through EO1 (not from the MAQHUE funds). Consequently, a conflict regarding the ownership of the 2,000 completed questionnaires – whether they should belong to the MAQHUE project or the EO1 – arose at the end of the survey. As a result, only 300 completed questionnaires were made available to the author for statistical analysis. The results of this analysis are summarized in Chapter 3, including a critique of the questionnaire design and modification. In spite of these problems, the questionnaire proved useful in confirming whether the targeted urban and suburban residents had received the information on air quality and the health impacts of air pollution.

Following the premature termination of the MAQHUE project in May 2003, the full results regarding air quality and health impacts (from the quality of life questionnaire) remained unavailable, hence the attitudes and experiences of Chiang Mai residents regarding air quality and its associated health impacts could not be adequately determined. With advice and assistance from Dr. Muthita Trakultivakorn, Faculty of Medicine, CMU, a study of the prevalence of respiratory diseases and allergies among school children in Chiang Mai (Chapter 4) was conducted. The questionnaire used in this study is one which has been standardized for use as part of an International Study of Asthma and Allergies in Childhood (ISAAC). Lung function tests were also conducted to investigate the prevalence of exercise-induced asthma among some asthmatic and non-asthmatic children. The tests were supervised by Dr. Trakultivakorn and two senior nurses (Mrs. Katirat Mahasu and Mrs. Siriboon Yavichai) from Maharaj Nakorn Chiang Mai Hospital (CMU hospital). The procedures implemented prior to and during the tests were approved by the MU Ethics Committee (Appendix 1).

During the MAQHUE project, the author was not able to visit the London Borough of Barnet, as originally planned, in order to learn about their experience of and approach to, air quality management. After the MAQHUE project was terminated, Prof. Brian Shutes (supervisor) received an agreement from Dr. Peter Louie, Senior Environmental Protection Officer (Acting), Air Science Group, for the author to visit the HK EPD in November 2004. Experience gained during the EPD visit included a comparison of air quality management approaches used by the HK EPD and Thai PCD, and this is summarised in Chapter 5. A critique of local air quality management in Chiang Mai was also conducted following the United Nations' Good Urban Governance approach. The EPD visit afforded the author a better understanding of urban air quality management. The lessons learned were used to evaluate the approaches used in Thailand, and led to the recommendation of improved air quality management measures for Chiang Mai.

In order to investigate the current level of prioritisation given to environmental problems, especially air pollution, by governmental organisations in Chiang Mai, a questionnaire was designed for officials of Sub-district Municipalities (SM) and Sub-district Administration Organisations (SAO). The results of the questionnaire enabled the identification of aspects of local administration, which should be improved to better manage air quality. The environmental management plans and policies [e.g. National Economic and Social Development Plan (NESDP), Government Management Plan (GMP), Environmental

Education (EE)] were also analysed. In addition, the provincial budgets for environmental projects in Chiang Mai were analysed. The results are summarized in Chapter 6.

The relevant results from each of the research components (Chapters 2 – 6) were used to formulate sustainable measures that could be implemented to improve local air quality management in Chiang Mai (Chapter 7). Recommendations for further studies are outlined in Chapter 8.

In conclusion, the tasks undertaken by the author for the MAQHUE project and included in this PhD thesis are limited to the modelling air quality in Chiang Mai (Phase I), and the statistical analysis of 300 completed questionnaires from the quality of life survey. The other components of the PhD project were initiated and conducted by the author, with support and assistance from the project supervisors and the staff of various organizations. The rationale, advantages and disadvantages of the methodology used for each research component are discussed in detail in the corresponding chapters.

In view of the scope and research approach adopted for this project as outlined above, the literature review is summarized as follows;

1.4 Air Pollution

1.4.1 Overview of Air Pollution in Thailand

The Kingdom of Thailand covers a land area of 513,115 square kilometers. It is bordered by Malaysia in the south, the Union of Myanmar (Burma) in the west and northwest, the Lao People's Democratic Republic to the northeast, and Cambodia to the southwest (Figure 1.2). It is located between latitude 05° 27´ north and 20° 27´ north, and between longitude 97° 21´ east to 105° 35´ east. Thailand is administratively divided into 76 provinces. The estimated population of Thailand in 1999 was about 62 million. The urban population was approximately 12 million and was concentrated in the capital and regional centers (Simachaya and Runghirunviroj, 2001). Bangkok Metropolitan, the capital city of Thailand, has the highest official population of around 6 million while the population in peripheral provinces (Samut Prakarn, Samut Sakorn, Nakohn Pathom, Pathum Thani, and Nonthaburi) is around 3 million.

Some studies related to air pollution arising from the use of motor vehicles were conducted in Bangkok and its peripheral provinces in the late 1990's (IPSR, 1999 and PCD, 2000b). Air pollution emissions in Thailand have also been estimated from figures for overall fuel consumption. A report on the Thailand Energy Situation of the Department of Energy Development and Promotion (DEDP) (2000) shows the estimated air pollutant emissions by sectors of energy consumption (Appendix 2). In 2000, the overall energy consumption for the nation was 61,733 ktoe (kilo ton of oil equivalent; 1 ton = 1.016 tonnes), which produced 146,560 kt of CO_2, 2,759 kt of CO, 640 kt of NO_x, 587 kt of SO_2 and 185 kt of suspended particulate matter (SPM). There are 7 sectors identified as producing air pollution in Thailand. These are the transportation, power, industry, agriculture, construction, mining, and residential and commercial sectors (PCD, 1994a). The two major air pollution sources in Thailand are motor vehicles and industry. The air pollution caused by motor vehicles is most important within large communities such as Bangkok and its peripheral areas, whereas air pollution sources from industry are scattered throughout the country (PCD, 1994a). The concentrations of air pollutants emitted from these sources, especially from industry, are relatively high. Sulphur dioxide, oxides of nitrogen and suspended particulate matter are the major air pollutants of concern.

1.4.1.1 Description of Air Pollution in Chiang Mai

Chiang Mai, the second largest province of Thailand, is located in the north of the country, between latitude 17° 21′ north and 20° 10′ north, and longitude 98° 40′ east and 99° 05′ east. It covers an area of 20,107 square kilometers (CMM, 2002a). There are approximately 600,000 people residing in 7 urban districts within Chiang Mai Comprehensive Urban Plan, and a population of approximately 1 million people residing in suburban areas (as of December 2004). The city of Chiang Mai is located in a valley at approximately 310 m above sea level, in a mountainous region in the north of the country (Figure 1.2). The province has grown rapidly in the past two decades. In 1985, the total population of Chiang Mai was 1,277,835, and in 2004, 1,630,769, with an exponential growth rate of 1.28% (source: Department of Local Administration, Ministry of Interior).

Source: Asia Travel (2006)

Figure 1.2 Map of Thailand indicating the position of Chiang Mai (arrow)

As elsewhere in Thailand, the most important mobile sources of air pollution in Chiang Mai are petrol and diesel cars. There were 559,476 registered motor vehicles in 1998. In 2001, more than 20,000 vehicles/hour commuted into and out of Chiang Mai city each day with traffic queues of more than 300 m in length during peak travel hours. PCD reported that 25% of private cars in Chiang Mai produce high concentrations of CO and hydrocarbons and 63% of diesel cars produce black smoke that exceeds Thai vehicle emission standards (Wangwongwatana and Warapetcharayut, 2001b). The results from these vehicle tests indicated that Chiang Mai has a severe air pollution problem, with the average concentration of most of the pollutants monitored being at, or above, the warning level of Thai vehicle standards.

In regard to point sources, there are 267 factories located in Chiang Mai Municipality (CMM) and more than 2000 factories located in the rest of the province (CMM, 2002b). Many of these include factories associated with food processing, wood carving and ceramics or pottery. Industries located in the community of the city of Chiang Mai include rice mills, steel/metal welding factories, garages (car painting, steel welding), concrete mixing and ceramics factories.

Agricultural burning, which also occasionally causes forest fires, is one of the key area sources of air pollution in Chiang Mai. In 1999, there were 1,934 events of forest fires in Chiang Mai province which covered an area of 20.9 km^2 (CMM, 2002b). Table 1.1 shows an emissions inventory of point, mobile and area sources in Chiang Mai municipal area in 2000 (CMM, 2002b).

Table 1.1 Chiang Mai Emissions Inventory, 2000

Pollutants (Tonnes/year)	**Point source**	**Mobile source**	**Area source**
PM_{10}	-	-	3.9
TSP	0.6	18	679
CO	2.7	17,204	11,509
SO_2	0.1	237	8.7
NO_2	0.4	2,232	414
HCs	-	1,506	23.5
VOC	-	-	2,437

Note: PM_{10} = particulate matter suspended in the atmosphere with an aerodynamic diameter size of less than 10 μm; TSP = total suspended particle; CO = carbon monoxide; SO_2 (sulphur dioxide); NO_2 = nitrogen dioxide; HCs = hydrocarbons; VOC = volatile organic compound.

Source: Chiang Mai Municipality (CMM) (2002b)

Mobile sources are a key source of CO, SO_2, NO_2 and hydrocarbons, whereas area sources are a major source of particulate matter. CMM categorised the sources of air pollution in Chiang Mai into the three main classes – point, area and mobile sources – as summarised in Table 1.2.

Table 1.2 Major air pollution sources in Chiang Mai Municipal area

Source type	Source
Point source	Factories Crematoria Incinerators
Area source	Chiang Mai International Airport and Airforce 41 Railway station Petrol stations Residential and commercial areas Agricultural burning Forest fires Domestic waste burning
Mobile source	Road traffic (cars, trucks and motorcycles)

Source: Chiang Mai Municipality (CMM) (2002b)

As identified by the PCD's air quality monitoring programme in the northern region [Chiang Mai (2 monitoring stations), Lampang (4 stations) and Nakorn Sawan (1 station); Figure 1.6], the main pollutants were PM_{10} and ozone (O_3) (PCD, 1999; PCD, 2000a). In 1999, the highest maximum average concentration of PM_{10} (24 hrs.) of 473 $\mu g/m^3$ was found at the Chiang Mai Provincial Hall, and was 4 times higher than the Thai standard for PM_{10} (120 $\mu g/m^3$) (Table 1.3). For O_3, the average maximum concentrations (1 hr) exceeded the standard at most of the monitoring stations. The highest O_3 concentration of 503 ppb was found at Ban Sobpard, in Lampang, which is near Mae Moh Power Plant. The highest SO_2 concentration of 374 ppb, which exceeded the standard (300 ppb SO_2), was found in Mae Moh district. In 2000, the highest PM_{10} concentration of 512 $\mu g/m^3$, which is about 4 times higher than the standard, was also found in Mae Moh. For Chiang Mai, the maximum PM_{10} concentration of 286 $\mu g/m^3$ recorded at Yuparaj School also significantly exceeded the standard. The highest average O_3 concentration of 131 ppb was also found in Mae Moh district, Lampang province but the SO_2 concentrations had generally decreased in Mae Moh and the highest concentrations were 174 ppb in 2000, 11 ppb in 2001 and 51 ppb in 2002. The atmospheric pollutants which are of most cause for concern in the northern region of Thailand are, in order of importance, PM_{10} and O_3. The highest PM_{10} concentrations were well above the standard of 120 $\mu g/m^3$ at 6 of the northern stations in 2001, and at all 7 stations in 2002. The highest O_3 concentrations were found in Ban Sobpard (113 ppb) in 2001 and at Chiang Mai Provincial Hall (161 ppb) in 2002 (PCD, 2002; PCD, 2003).

Table 1.3 National Air Quality Standards of Thailand

Ambient Air Quality Standards of Thailand (1995)										
Pollutants*	**1- hr average**		**8 - hr average**		**24 - hr average**		**1- month average**		**1 - year average****	
	mg/m^3	**ppm**	**mg/m^3**	**ppm**	**mg/m^3**	**ppm**	**mg/m^3**	**ppm**	**mg/m^3**	**Ppm**
1. Carbon Monoxide (CO)	34.2	30	10.26	9	-	-	-	-	-	-
2. Nitrogen Dioxide (NO_2)	0.32	0.17	-	-	-	-	-	-	-	-
3. Sulphur Dioxide/[a] (SO_2)	0.78	0.30	-	-	0.30	0.12	-	-	0.10	0.04
4. Total Suspended Particulates (TSP)	-	-	-	-	0.33	-	-	-	0.10	-
5. Particulate matter (< 10μm) (PM_{10})	-	-	-	-	0.12	-	-	-	0.05	-
6. Ozone (O_3)	0.20	0.10	-	-	-	-	-	-	-	-
7. Lead (Pb)	-	-	-	-	-	-	1.5	-	-	-

Note: * At 1 standard pressure and 25 ^{O}C

** geometric mean

/a 1- hr SO_2 Standard: 1.3 milligram/cubic meter for Mae Moh area; 0.78 milligram/cubic meter, elsewhere

Source: Notification of National Environmental Board No. 10 (1992) under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1992) published in the Royal Government Gazette No. 112 Part 52 dated May 25, B.E.2538(1995)

According to the national air quality standards of Thailand (Table 1.3), the pollutants listed for regulation include CO, NO_2, SO_2, total suspended particulates (TSP) and PM_{10}, O_3 and lead. The characteristics and sources of each pollutant are summarized in Table 1.4.

Table 1.4 Characteristics and sources of major air pollutants in Thailand

Pollutant	Characteristics and Sources
CO	A colourless, odourless, and poisonous gas that is produced by the incomplete combustion of carbon-containing fuels (Ayers, 1998). In Thailand, CO emissions are predominantly produced by the residential and commercial sectors, accounting for 74% of the year 2000 total emissions (DEDP, 2000). However, the high CO concentrations along roadsides are undoubtedly produced by motor vehicles.
NO_2	NO is produced by the oxidation of nitrogen during combustion. Subsequently, it is further oxidized to NO_2. NO_2 is the first and most immediate reaction product of the atmospheric oxidation of the NO emitted by human activities, namely motor traffic, power station and home and industrial combustion processes (Derwent, 1999). The transport and power sectors are the main sources of NO_x emission in Thailand. The respective NO_x emissions from transport, power and industrial sectors were 214, 153 and 138 kT, which accounted for 34%, 24%, and 22% of the total (DEDP, 2000).
SO_2	A non-flammable, non-explosive and colourless gas (Wark *et al.*, 1998). The combustion of fossil fuels is a major source of sulphur dioxide, especially of coal and fuel oil (Harrison, 1996). Petrol and diesel fuels have a relatively small sulphur content, however they can increase SO_2 concentrations alongside busy roads. The predominant source of SO_2 emissions in Thailand are fossil-fuelled power stations, which in 1999, respectively contributed 840 and 616 kT (coal only) accounting for 70% of the total for the country (DEDP, 2000). However, in Thailand during the past 3 decades, the SO_2-concentration trend has been downward.
TSP&PM_{10}	Particulate matter (PM) is categorised by its size distribution. All sizes of suspended particles in the air are termed total suspended particulates (TSP). PM_{10} is, approximately, the PM suspended in the atmosphere with an aerodynamic diameter of less than 10 μm. The sources of particles are both natural (e.g. sea spray, windblown mineral dust), and anthropogenic (soot, smoke, road dust and products of the conversion of gases from combustion of fossil fuels (e.g., SO_4^{2-} and NO_3^-) and PM from quarrying processes) (Prospero *et al.*, 1981 cited by Koutrakis and Sioutas, 1996). In Thailand, suspended particulate matter is estimated by energy consumption from which power and transport sectors in 1999 contributed about 88% and 6% of the total respectively (DEDP, 2000).
O_3	O_3 is a colourless and odourless gas. Ground-level O_3 occurs as a result of the chemical reactions between oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and air in the presence of sunlight. In a polluted environment, O_3 concentrations are normally high due to its precursors, mainly VOCs and NOx (especially from vehicle exhaust) (DMTI Spatial, 2004). High O_3 concentrations were found in Thailand, especially in Bangkok (Wangwongwatana and Warapetcharayut, 2001a).
Lead	For decades, exhaust from motor vehicles that used leaded gasoline was the major source of atmospheric lead in Thailand. Leaded gasoline has no longer been available in the country since 1 January 1996. The lead content in gasoline had been gradually reduced from 0.84 g/l before 1984, to 0 g/l in 1996. Methyl tertiary butyl ether (MTBE) is normally used instead of lead to boost gasoline octane rating. Consequently, the ambient lead concentrations, observed by PCD, have declined (Wangwongwatana and Warapetcharayut, 2001a).

1.4.2 Health Impacts – Possible Consequences of Exposure to Air Pollution

Human health can be adversely affected by atmospheric pollution. For this reason, a consideration of the expected consequences of air pollution episodes are an important consideration during the development of air quality management plans. Health impacts caused by air pollution include eye irritation, skin rashes, itchiness, respiratory and cardiovascular diseases, hypertension and various forms of cancer. Air pollution can also cause the exacerbation of asthma and coronary disease, increased incidence of chronic bronchitis and acute respiratory illnesses, and impairment of lung function (Schwartz, 2001; Heinrich, 1999; Ostro *et al.*, 1999, Herbarth *et al.*, 1997). Infants, the elderly, and those suffering from chronic respiratory conditions such as asthma, bronchitis and emphysema are especially vulnerable to polluted air. A number of studies have focused on respiratory diseases, such as asthma, in children (Mortimer *et al.*, 2002; Gehring *et al.*, 2002; Hirsch *et al.*, 1999) and cardiovascular disease in the elderly (Liao *et al.*, 1999). Most of these studies focused on the adverse health effects caused by particulate pollution. Since, there is a lack of association between mortality and the concentrations of other pollutants, particularly SO_2. Independent mortality and morbidity effects for particulate matter have been studied worldwide, particularly in the USA, and possible mechanisms for PM toxicity are reasonably developed (DoH, 1998). Furthermore, the association of O_3 and both total and cause-specific mortality (such as respiratory and cardiovascular diseases) is well studied whereas the effects of NO_2 on mortality remains unclear.

In 1994, the World Health Organisation (WHO) provided a summary of health outcomes associated with changes in ambient O_3 concentration in epidemiological studies (as shown in Table 1.5). The UK Department of Health (DoH) (1998) also advised that caution must be exercised in applying the results shown in these tables. The relationship defined in the table is linear in terms of the concentration of O_3, however, the dose-response curve becomes steeper as the concentration increases.

Several studies have shown that ambient particulate pollution is associated with daily mortality and hospital admissions (Fusco *et al.*, 2001; Schwartz, 2001; Simpson *et al.*, 2000; McDonnell *et al.*, 2000; Pope III *et al.*, 1999). Le Tertre *et al.* (2002) commented on the results of recent epidemiological studies, which showed that ambient air pollution adversely affects human health, even at levels close to or lower than the current national standards of European countries. Of the common atmospheric pollutants, particulate matter is the most consistently associated with mortality. For example, Simpson *et al.* (2000) reported that the US epidemiological studies showed a consistent 1% increase in daily mortality associated with a 10 $\mu g/m^3$ increase in daily average PM_{10} levels (24-hr average concentrations).

Table 1.5 Summary of health outcomes associated with changes in O_3 concentrations in epidemiological studies (DoH, 1998)

Health outcomes associated with changes in ambient concentration in epidemiological studies	**Change in 1h O_3 ($\mu g/m^3$)**	**Change in 8h O_3 ($\mu g/m^3$)**
Symptom exacerbations among healthy adults or asthmatics – normal activity		
25% increase	200	100
50% increase	400	200
100% increase	800	300
Hospital admissions for respiratory conditions		
5% increase	30	25
10% increase	60	50
20% increase	120	100

Health outcomes associated with controlled ozone exposures	**O_3 concentration ($\mu g/m^3$) at which health effect expected**	
Averaging	**1h O_3**	**8h O_3**
FEV1 (active, healthy, outdoors, most sensitive 10% of healthy children and young adults)		
5%	250	120
10%	350	160
20%	500	240
Inflammatory changes (neutrophil influx) (healthy young adults at >40 1/min outdoors)		
2-fold increase	400	180
4-fold increase	600	250
8-fold increase	800	320

The UK Department of Health (DoH) (1998) summarised estimates of the effects of daily mean particulate pollution as shown in Table 1.6. There is a 1% increase in daily mortality rate for every increase of 10 $\mu g/m^3$ PM_{10}. However, as previously stated, the effect estimates observed in the UK and Europe are lower than those observed in the US studies (DoH, 1998). Furthermore, the application of these rates to the estimation of mortality and morbidity resulting from air pollution in Asian countries may create additional uncertainties. For instance, WHO estimated that, in 2001, 800,000 people around the world died prematurely from lung cancer, cardiovascular and respiratory diseases caused by outdoor air pollution and 4.6 million lost life-years worldwide. Two thirds of these deaths and lost life-years were determined to occur in Asian developing countries (WHO, 2002). The estimates were based mainly upon the results of research conducted in Europe and North America [Health Effects Institute (HEI), 2004]. There are differences, between developing Asian and developed countries in Europe and North America, in the nature of air pollution, the conditions and magnitude of pollution exposure, and health status, particularly, the accessibility to and efficiency of health care.

Table 1.6 Summary of estimates of health effects of changes in daily mean particulate pollution (DoH, 1998)

	% change in health indicator per each 10 $\mu g/m^3$ increase in PM_{10}
1. Increase in daily mortality	
• Total deaths	1.0
• Respiratory deaths	3.4
• Cardiovascular deaths	1.4
2. Increase in hospital usage (all respiratory admissions)	0.8
• Emergency department visits	1.0
3. Exacerbation of asthma	
• Asthmatic attacks	3.0
• Bronchodilator use	2.9
• Hospital admissions	1.9
4. Increase in respiratory symptoms	
• Lower respiratory	3.0
• Upper respiratory	0.7
• Cough	1.2
5. Decrease in lung function	
• Forced expired volume	0.15
• Peak expiratory flow	0.08

Note: Effects of PM_{10} on indicators of ill-health (from Dockery and Pope (1994) – a meta-analysis of studies on the effects of particles, each estimate is from a combination of two or more studies)

HEI (2004) identified 138 papers (published between 1980 – 2003) that present original estimates of the health effects from outdoor air pollution in eight Asian countries – China (including HK SAR and Taipei), India, Indonesia, Japan, South Korea, Malaysia, Singapore and Thailand. Most of these studies were conducted in China, South Korea and Japan. The study designs were predominately either cross-sectional prevalence studies (of chronic respiratory symptoms or pulmonary function) or time-series studies (of the effects of short-term exposure on daily mortality or hospital admissions). Generally, cross-sectional studies measure the prevalence of disease. They are relatively easy and economical to conduct and are useful for investigating exposures that are based on fixed characteristics of individuals such as ethnicity and socioeconomic status. However, it is sometimes difficult to assess the reasons for associations demonstrated in cross-sectional studies. The comparison of results from cross-sectional studies in different countries can be further hindered by the absence of standardization in the survey methods (Beaglehole *et al.,* 1993). The International Study of Asthma and Allergies in Childhood (ISAAC) (a cross-sectional study) was made to be applicable across different countries by using a standardized questionnaire.

This review focuses on three major respiratory and allergic diseases - namely asthma, rhinitis and eczema – as they are included in the ISAAC questionnaire as part of the cross-sectional prevalence study of respiratory and allergic diseases among schoolchildren in

Chiang Mai. Their definitions and symptoms are summarized in Table 1.7. Air pollutants at concentrations typical of polluted cities can trigger bronchoconstriction, increase airway responsiveness, and magnify allergic responses, especially among asthmatic and allergic subjects [the Global Initiative for Asthma (GINA), 2002]. Some of the cross-sectional studies conducted in Asia (cited by HEI, 2004) are summarised in Table 1.8.

Table 1.7 Definitions and symptoms of asthma, rhinitis and eczema

Diseases	Definition and Symptoms
Asthma	A chronic inflammatory disorder of the airways in which many cells and cellular elements play a role. The chronic inflammation causes an associated increase in airway hyperresponsiveness that leads to recurrent episodes of wheezing, breathlessness, chest tightness, and coughing, particularly at night or in the early morning. These episodes are usually associated with widespread but variable airflow obstruction that is often reversible either spontaneously or with treatment (GINA, 2002). Allergens that can trigger asthma attacks include foods, dust, mould, feathers, animal dander (small scales from animal hair or feathers); irritants in the air such as dirt, cigarette smoke, gases, and odours; other triggers include respiratory infections such as colds, flu, sore, throats and bronchitis; and weather such as very cold air, windy weather, or sudden changes in weather (Shutes, 2002).
Rhinitis	An inflammation of the lining of the nose. Inflamed mucous membranes cause swelling and block airflow. It also causes over-reactivity of the glands in the mucous membrane causing excessive mucus production and a watery discharge. The delicate lining of the eyes can also be inflamed and irritated if allergens enter the eyes. (The UK National Health Service, 2005). Summer hay fever is a form of rhinitis and also called seasonal allergic rhinitis, an allergy to grass, weed and tree pollens, moulds, hair, feathers, skin scalds (dander), house mites, house dust or other airborne pollutants. The hay fever symptoms include sneezing, stuffiness and a watery discharge from the nose. (Morris, 2005).
Eczema	An allergic condition that affects the skin. The eczema symptom in mild cases is a patch of sore skin, but in severe cases extensive areas of skin are inflamed with an unbearable itchiness. People with other allergies such as hay fever are prone to eczema. There are two most common forms of eczema – atopic dermatitis and contact dermatitis. Atopic dermatitis (AD) (atopic or infantile eczema) that occurs in people with dry and rough skin may be caused by a variety of allergens, and normally commences in childhood. Food (mainly in children), house dust mite and probably genetic predisposition to atopy* are risk factors for AD. In children, the inflamed and itchy skin caused by AD can be affected with impetigo especially on the flexural areas of arms, legs and ankles (NHS website, date not specified). Contact dermatitis, which usually affects adults, occurs when the skin reacts to contact with chemical substances (Hicks, 2005).

Note: * Atopy is defined as the genetic tendency to develop the classic allergic diseases – atopic dermatitis, allergic rhinitis (hay fever) and asthma. Atopy involves the capacity to produce immunoglobulin E (IgE) antibodies in response to common environmental allergens such as dust mite, grass pollen, food allergen, etc. (MedicineNet, 2006). Generally, people with atopy tend to produce abnormal (excessive) amounts of IgE in response to an allergen (GINA, 2002).

Table 1.8 Summary of cross-sectional studies of air quality and health effects in Asia

Citation, Study location	Period, Sample	Exposure	Health outcome	Summary of findings
Zhang *et al.* (2000), China (Guangzhou, Wuhan, Lanzhou, and Chongqing,)	1993-1996, 7557 elementary school students	NO_x, SO_2, TSP, PM $_{(2.5, 10\text{-}2.5, 10)}$	Wheeze, asthma, bronchitis, hospitalization due to respiratory diseases, persistent cough, persistent phlegm	Standardized questionnaires revealed positive associations between respiratory morbidity and outdoor concentrations of $PM_{10\text{-}2.5}$, NO_x and SO_2,
Tam *et al.* (1994), Hong Kong	1989 – 1990, 423 children (mean age, 10.85 yrs)	NO_2, O_3, SO_2, TSP and PM_{10}	Bronchial responsiveness (FVC, FEV_1)*	Bronchial hyperreactivity after histamine challenge was more common among children living in a more polluted district even when results were controlled for wheeze, asthma, home tobacco smoke, and socioeconomic factors.
Yang *et al.* (1998), Taipei, China	1994-1995, 1071 primary school children (460 in polluted area, 611 in control area)	Petrochemical air pollution (PM, SO_2, NO_2 and acid aerosols)	Respiratory symptoms among primary school children	Primary school children living in a petrochemical area were exposed to significantly higher levels of PM, SO_2, NO_2 and acid aerosols than children in a control area. The exposed children had significantly more upper respiratory tract symptoms and asthma. A causal relation could not be confirmed.
Chew *et al.* (1999), Singapore	1994, school children (2030, 6-7 yr; 4208, 12-15 yr)		Asthma and allergies	In data from an ISAAC questionnaire, outcomes were associated with demographic and socioeconomic differences, but not with air pollution or environmental factors.
Pothikamjorn *et al.* (2000), Bangkok	1998-1999, 290 high school students exposed to a 24-hr average of 170 $\mu g/m^3$ PM_{10}	PM_{10}	Allergic symptoms, allergic skin sensitivity, lung function	A significant increase in school absence and medical expenses was associated with high PM_{10} exposure.
Wongsurakiat *et al.* (1999), Bangkok	1996-1997, 629 traffic policemen and 303 control subjects		Respiratory symptoms, lung function	Non-smoker traffic policemen had significantly higher prevalence of cough, phlegm, rhinitis symptoms, and abnormal air flow than non-smoker controls. Mean FEV_1 and FVC values were also significantly lower for the policemen. Policemen who did not wear protective masks had significantly increased prevalence of abnormal FEV_1 and FVC compared with mask-wearing policemen.

Source: Health Effects Institute (2004); FVC = forced vital capacity (the maximum volume of gas that can be expired by the subject as forcefully and rapidly as possible, after a maximal inspiration to lung capacity (Ruppel, 1994)) * FEV1 = forced expiratory volume in 1 second (the volume of gas expired over a one-second interval from the beginning of the FVC maneuver (Ruppel, 1994).

The data from the International Study of Asthma and Allergies in Childhood (ISAAC, 1998) showed that there are large differences in asthma prevalence (percentage of the population with asthma) among different populations, the highest prevalence being found in the UK, New Zealand and Australia. Trakultivakorn (1999) investigated the prevalence of asthma among children in Chiang Mai using the standardised ISAAC questionnaire for asthma and allergies. For asthma, it was found that prevalence based on wheezing over the past 12 months in children 6-7 years old and 13-14 years old, was 5.5% and 12.6% respectively, which is slightly lower than the asthma prevalence results produced by a similar ISAAC study in Bangkok. In addition, annual in-patient data from the Chiang Mai Health Office showed an increase in the number of asthmatic patients from 1,359 in 1995 to 1,670 in 2001.

Regarding rhinitis in Chiang Mai, pollen from longan trees (*Euphoria longana* Lam.) may cause hay fever symptoms in some schoolchildren in Saraphi district during March and April. Trakultivakorn (1999) reported that the prevalence of allergic rhinitis in children aged 6-7 years and 13-14 years in Chiang Mai were 18.5% and 38.3%, respectively. The prevalence of eczema in children aged 6-7 years and 13-14 years, based on the occurrence of rash in flexural areas, were 18.5% and 38.3% respectively (Trakultivakorn 1999).

The Ministry of Public Health (MOPH) reported that the occurrence and mortality from respiratory diseases in Thai people were 19,888 (32.9 per 100,000 population) in 1997 and 23,417 (37.7 per 100,000 population) in 2001. In 2000, almost 25 million people suffered from respiratory diseases in Thailand (not including Bangkok Metropolitan). This included 1.38 million in the north of Thailand. Chiang Mai Public Health Office data for 1999 indicated that 42,739 people out of every 100,000 (42.7%) in Chiang Mai suffered from respiratory problems. In comparison, the data for 1994 showed 33,000 of every 100,000 (33%) of the population had impaired respiratory health. In addition, the occurrence of lung cancer in-patients in Chiang Mai increased from 190 to 555 from 1996 to 2001 – although much of this may be related to changes in smoking patterns. Wiwatanadate and Chunram (2002) reported that the top 5 causes of death in Chiang Mai in 2001 were AIDS, cardiovascular diseases, respiratory diseases, cancers, and suicides, respectively. In Maharaj Nakorn Chiang Mai Hospital, the number of in-patients with respiratory diseases increased dramatically from 3,071 to 4,739 between 1995 – 2000. Wiwatanadate and Chunram (2002) speculated that some of this increase was due to increases in exposure to air pollution.

In conclusion, the review of previous health studies shows that air pollution is widely accepted as being harmful to human health. However, there are uncertainties over specific causes and effects, especially in the area of combined or synergistic effects and it is acknowledged that, in many studies of health effects due to air pollution, there is an incomplete picture of the patterns of exposure. In many studies, the effects from individual pollutants have been analysed separately and consequently the epidemiology of the health effects of mixtures of air pollutants has been poorly developed (DoH, 1997). It is generally agreed that effective air quality management should lead to a reduction in exposure to harmful pollutants.

1.5 Air Quality Management

1.5.1 Environmental Management Responsibilities in Thailand

Thailand announced its first environmental management legislation in 1975 with the Enhancement and Conservation of National Environmental Quality Act B.E. 2518 (1975). As a result of this legislation, the Office of the National Environment Board was established under the supervision of the Prime Minister's Office to manage the environment. In 1992, the Royal Thai Government announced the replacement of the 1975 legislation with the Enhancement and Conservation of National Environment Quality Act B.E. 2535 (1992) (NEQA). Following this Act, the Ministry of Science, Technology and Environment (MOSTE) was established. To better understand the roles of regional, provincial and local governments in Chiang Mai, the institutional aspects of environmental management in Thailand were reviewed and are summarised as follows;

1.5.1.1 Responsibilities of Ministry of Natural Resources and Environment

In 2002, MOSTE was restructured to become the Ministry of Natural Resources and Environment (MONRE), following the Act Amending Ministry, Sub-ministry and Department B.E. 2545 (2002) and Government Reorganization Act B.E. 2545 (2002). The powers and responsibilities given to MONRE are concerned with the preservation, conservation and rehabilitation of natural resources and environment, management and sustainable use of resources and implementation of other government services [Office of the Permanent Secretary of Natural Resources and Environment (OPS), 2004]. Major government departments with a responsibility for environmental issues (including air pollution) in Thailand are as follows;

i) Pollution Control Department

The Pollution Control Department (PCD) formulates and administers national pollution management plans to control, prevent and mitigate environmental pollution. Its major responsibilities are the formulation of national policy and plans for the promotion, enhancement and conservation of environmental quality, including the establishment of environmental quality and emission standards. Furthermore, PCD monitors environmental quality, particularly air and water quality, and is responsible for taking action on public complaints related to pollution. Its pollution control functions are mainly specified in NEQA. As part of its role, PCD is empowered to investigate whether industries are complying with required effluent standards. For instance, PCD must ensure, through periodic inspections, that self-monitoring programmes for industrial wastewater discharges and atmospheric emissions are resulting in the maintenance of accurate and certifiable records. PCD is also responsible for the periodic review of emission standards and, where necessary, making recommendations for changes to their specification and design. However, the legal remit of the PCD deals with ambient air quality as well as with emissions (OPS, 2004).

ii) Office of Natural Resources and Environmental Policy and Planning

The Office of Natural Resources and Environmental Policy and Planning (ONEP), under MONRE, aims to strengthen the national economy while promoting sustainable development and enhancing the quality of life. It is responsible for developing policy and plans for the management of natural resources, environmental enhancement and conservation in compliance with NEQA and other related laws. Significant development and construction projects, within both the government and private sectors, are required to submit Environmental Impact Assessment (EIA) reports to ONEP.

The office also administrates the Environmental Fund (EF) in order to support natural resource and environment management policies and plans at all levels (OPS, 2004). According to NEQA, the EF is made up from various sources such as the Fuel Oil Fund; the Revolving Fund for environmental development and quality of life; service fees and penalties collected under the terms of the Act; government grants; and donations (from both domestic and foreign origin). Any grant or loan for government or local projects must be requested through a provincial action plan for environmental quality management and then be proposed to ONEP (Seatec International Ltd., 1995). The EF was established in 1992 with an initial capital of THB5,000 million. During 1993 – 1995, the Thai government subsidised THB1,250 million, and, in 1994, the Japan Bank of International Cooperation (JBIC) provided USD100 million as a loan to the EF. In 2004, the accumulated fund stood at THB14,200 million (Poboon, 2004).

iii) Department of Environmental Quality Promotion

The Department of Environmental Quality Promotion (DEQP), MONRE, works to enhance environmental quality through research, development, training, strengthening of public awareness and technology transfer with the aims of improving the quality of life and promoting sustainable management. The department conducts public relations activities in the areas of natural resources and the environment and also acts as the Natural Resources and Environmental Information Centre for collecting and disseminating environmental information. In addition, DEQP serves as the Centre for Cleaner Production (OPS, 2004).

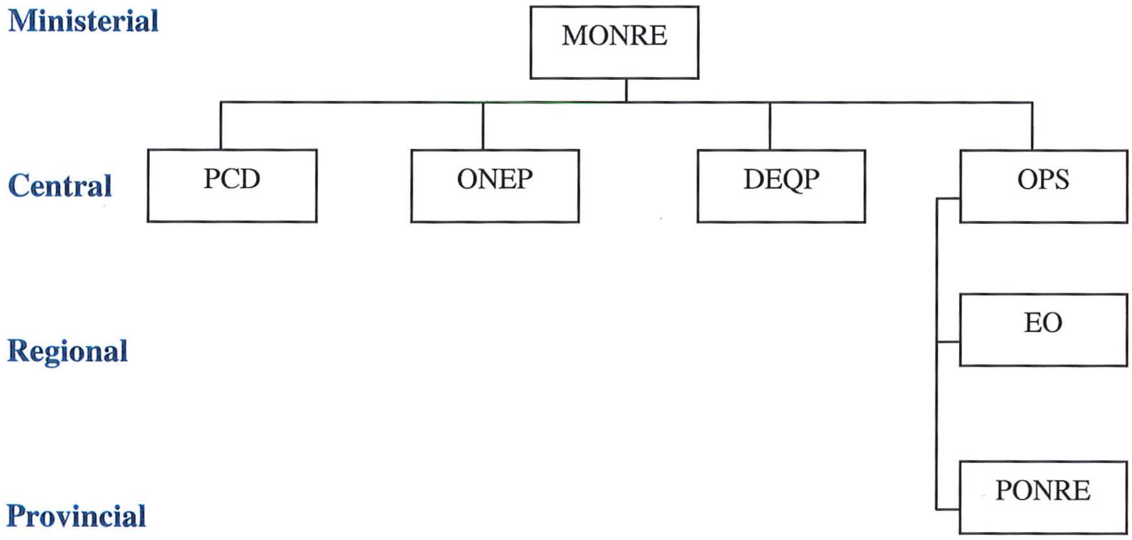
iv) Regional Environmental Offices

Under the Office of the Permanent Secretary (OPS), MONRE, there are 16 Regional Environmental Offices located in different parts of Thailand. The responsibilities of the regional offices are: to formulate regional environmental management plans; coordinate and evaluate activities related to regional and provincial management plans; develop the regional environmental information system; consult and manage technical knowledge and environmental measurements together with the encouragement of other activities in accordance with sound environmental management; monitor and inspect environmental quality; promote public participation and create environmental networks; and develop local environmental technology appropriate for each region (OPS, 2004). The Environmental Office Region 1 (EO1), located in Chiang Mai, has its responsibilities in 4 provinces (Chiang Mai, Chiang Rai, Lamphun and Mae Hong Son).

v) Provincial Offices for Natural Resources and Environment

The Provincial Offices for Natural Resources and Environment (PONRE) are located in each of the 75 provinces throughout Thailand. Their major responsibilities include: formulation of provincial environmental management plans and provincial environmental quality management action plans; evaluation, monitoring and inspection of provincial environmental quality; conservation and protection of wildlife; activities as required by the National Forest Reserve Act, the Plantation Act, the National Community Forest Act, and other related acts; monitoring, inspection, control and maintenance of water resources;

provision of public education and fostering of public participation in the conservation, preservation and development of natural resources and the environment; and cooperation with other organizations regarding natural resources and the environment (OPS, 2004). The Chiang Mai PONRE was established in 2003. The overall organisational framework for the administration of environmental management under the Ministry of Natural Resources and Environment is shown in Figure 1.3 below.



Note:	MONRE	Ministry of Natural Resources and Environment
	PCD	Pollution Control Department
	ONEP	Office of the Natural Resources and Environmental Policy and Planning
	DEQP	Department of Environmental Quality Promotion
	OPS	Office of the Permanent Secretary
	EO	Environmental Office
	PONRE	Provincial Office of Natural Resources and Environment

Figure 1.3 Administrative levels of governmental organizations, under the Ministry of Natural Resources and Environment, with a responsibility for environmental management and control in Thailand.

1.5.1.2 Responsibilities of Ministry of Industry

i) Department of Industrial Works

The Department of Industrial Works (DIW) regulates industrial activities pursuant to various rules and regulations under the Factory Act B.E. 2535 (1992). Factories are required to register with DIW and obtain a permit to operate, which needs to be renewed every 5 years. DIW has authority to cancel the permit and close down any factories that do not follow factory regulations, or that pollute the environment causing harm to public health. Moreover, DIW provides technical advice to industry including the fields of environmental management and occupational health and safety. The DIW's environmental management brief includes extending its capability to control and counsel industry in the use of appropriate technology for sustainable development (PCD, 1997a). With regards to pollution control, DIW has the following strategies: preparation of a master plan for pollution control for each of water, soil and air; implementation of various economic instruments (emission charges, user charges, tradable permits etc.) under the Polluter Pays Principle; encouragement of manufacturers to use cleaner technology together with reduction and reuse techniques; assistance in the installation of pilot treatment plants for small scale factories; provision of information and expertise in waste management; and establishment of regional environment laboratories and waste management centers (The Royal Thai Government, 1999). DIW has provincial offices throughout Thailand including Chiang Mai (Chiang Mai Provincial Industry Office). Figure 1.4 illustrates administrative levels of governmental organizations, under the Ministry of Industry, relating to industrial pollution control in Thailand.

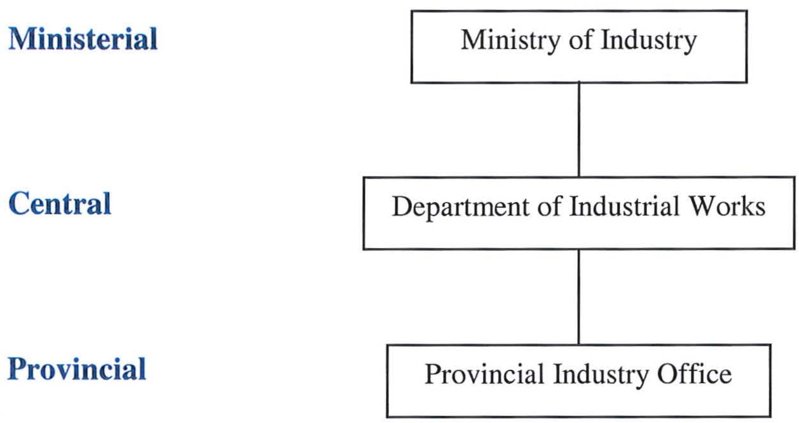


Figure 1.4 Administrative levels of governmental organizations, under the Ministry of Industry, relating to industrial pollution control in Thailand

1.5.1.3 Responsibilities of Ministry of Interior

Two central departments under the Ministry of Interior that also have responsibilities for local air quality management in Chiang Mai are the Department of Public Works and Town and Country Planning (DPT) and the Department of Local Administration (DOLA).

i) Department of Public Works and Town and Country Planning

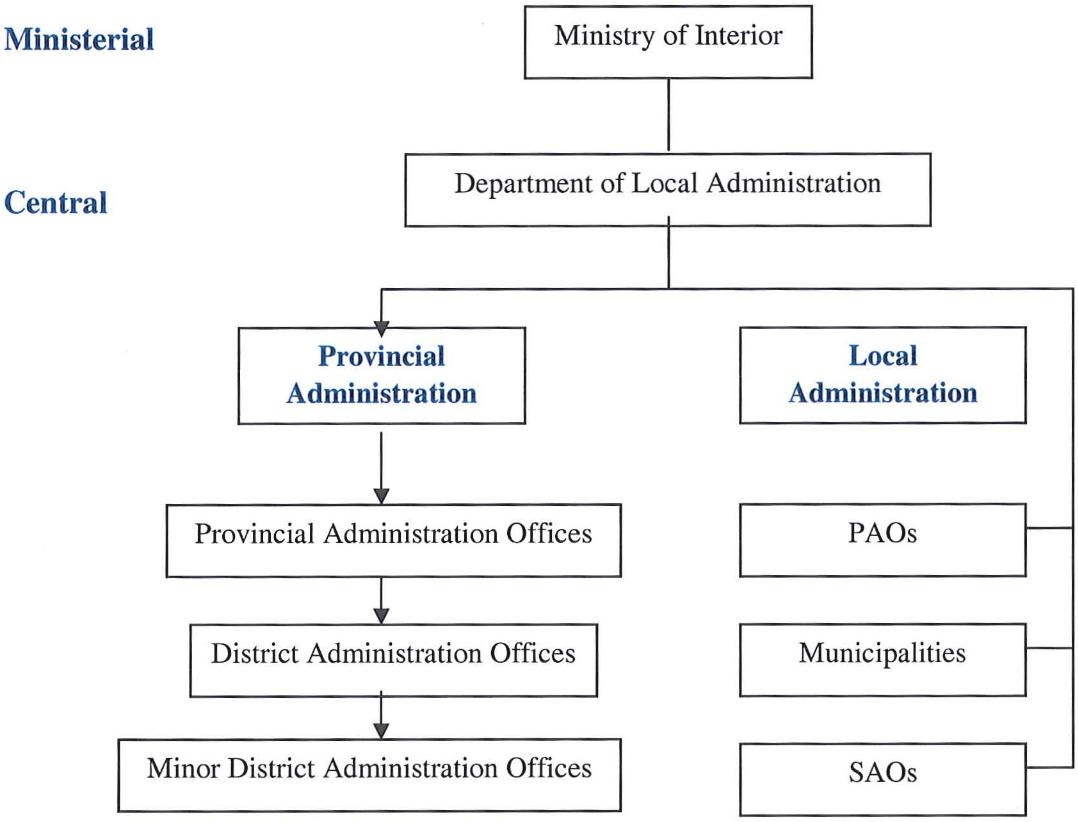
After a major reform of governmental organization in 2002, the Department of Public Works was amalgamated with the Department of Town and Country Planning to form DPT. DPT controls the zoning of each province under the Town and Country Planning Act (TCPA) (1975). This is an important piece of zoning legislation that provides a statutory framework for town and country planning at two levels: planning and implementation. Primarily, a general program for town and country planning in any locality can be initiated either by the local government or by DPT with the aim of preparation and implementation of a Master Town Plan (MTP), which will come into effect after approval by the Town and Country Planning Committee and then be formally promulgated by the Minister of Interior. In most cases, the aim of MTP implementation is to designate various zones on official maps, together with a set of rather broad and vague prescriptions for land use requirements or prohibitions in each zone (Seatec International Ltd, 1995). Nine zones are normally designated in most MTPs: i) open space zone; ii) low density residential zone; iii) average density residential zone; iv) high density residential zone; v) industrial zone; vi) rural and agricultural zone; vii) educational institution zone; viii) religious establishment zone; and ix) official establishment and public utility zone. In terms of environmental aspects, factories are prohibited in any residential zones. But there is an exception to this rule for "factories which can be operated without causing nuisances according to the law on public health or without causing pollution to the community or environment" (Seatec International Ltd, 1995). This may explain why there are so many factories located in the residential areas of Chiang Mai, including those which contribute to air pollution problems. Examples of some such factories are shown in Chapter 6.

The Provincial Offices of Public Works and Town and Country Planning are located in each of the 75 provinces throughout Thailand.

ii) Department of Local Administration

The Department of Local Administration (DOLA), operating under the Ministry of Interior, is in charge of the supervision and co-ordination of both provincial (i.e., provincial governors, Provincial Administration Organisations (PAO)) and local (i.e., City Municipalities (CM), Sub-district Municipalities (SM) and Sub-district Administration Organisations (SAO)) government organizations. The DOLA organization structure is summarized in Figure 1.5. Table 1.9 shows administrative levels of provincial and local governments in Chiang Mai Province. DOLA supports the decentralization of authority to local offices, on issues such as local income and taxes [Department of Provincial Administration (DOPA), 2001]. Since the promulgation of the 1997 Constitution, recent government developments aim to decentralize power and devolve responsibilities and finances to local governments (i.e. Provincial Administrative Organisation (PAO), Sub-district Administrative Organisations (SAO), and municipalities). The Constitution also promotes public participation, at a local level, in the design and implementation of policies, programmes, and projects. (Mutebi, 2005). The heads of local governmental organizations are appointed by public election (e.g. mayor (for municipal organizations); chief executive (for PAOs and SAOs) and his/her council team).

In each province, one provincial governor is appointed by the central government (Ministry of Interior), with the exception of Bangkok where the governor is publicly elected. The Provincial Administration Office controls and supports plan and policy implementation for each district and minor district, including coordinating and overseeing local government organisations (DOPA, 2001). In addition, it is responsible for establishing the strategic plan for provincial development, based on the National Economic and Social Development Plan (NESDP) and the specific needs of the province (e.g. forest conservation, wastewater treatment plants). The strategic plan is then distributed to government organizations at national, provincial and local levels. Based on the proposed development projects initiated by different central government organizations in the province (eg. EO1, PONRE, DPT), related ministries allocate annual funds to the province to form the Provincial Budget. As Chiang Mai is included in the CEO Governor Programme, under the Office of the Prime Minister (OPM), there are special funds (CEO Governor Budget) allocated to Chiang Mai province for special or urgent projects such as unexpected natural disasters, flooding, air pollution abatement, forest fire prevention, etc. At present, Mr. Suwat Tantibhat is the Chiang Mai CEO governor (pers. comm. with Mr. Sakulpetch Pikulprasert, Chiang Mai Provincial Administration Office; as of December 2005). Moreover, the District and Minor District Administration Offices, under the Provincial Administration Office, have responsibility for district administration, including local development, civil registration and identification card service, disaster relief, and civil defense volunteers, etc.



Source: Department of Provincial Administration (DOPA) (2001)

Note: PAOs Provincial Administration Organisations; SAOs Sub-district Administration Organisations

→ Line of Command —— Line of Supervision and co-ordination

<u>Figure 1.5</u> Administrative levels of governmental organizations, under the Ministry of Interior, relating to provincial and local administration in Thailand

Table 1.9 Provincial and local administrative levels of government organisations in Chiang Mai

Administrative level	Government organisation	Head of organisation
Provincial Administration	Provincial Administration Office (Governor's office) (1) District & Minor District Administration Offices (21 & 2, respectively)	Governor (appointed by central government, subject to periodic transfer to other provinces) Chief Officer (appointed by central government)
Local Administration	Provincial Administration Organisation (1) Chiang Mai (*Nakorn*) Municipality (1) Sub-district Municipalities (28) Sub-district Administration Organisations (186)	Chief Executive (elected) Mayor (elected) Chief Executive (elected) Chief Executive (elected)

The Provincial Administration Organisations (PAO) have the responsibility to oversee and systemise public services for the benefit of local communities, these roles being specified in the Provincial Act B.E. 2540 (1997). Additionally, the Decentralisation Act B.E. 2542 (1999) further adds to these responsibilities as follows;

- Promotion of public participation in the development of local areas
- Establishment and maintenance of wastewater treatment system
- Establishment and maintenance of solid waste disposal system
- Environmental management and pollution control
- Promotion of tourism
- Construction and maintenance of roads and waterways connecting localities [Thailand Environment Institute (TEI), 2003].

PAOs also have the role of conducting the local projects that are beyond the abilities of the SMs and SAOs in their province (e.g. large landfill site construction projects), however, the case where project areas and responsibilities involve more than two SAOs, prior approval must be obtained from each of these bodies. PAOs can also provide budgetary assistance to local governments where necessary (TEI, 2003). Moreover, PAOs can work together with other provincial authorities such as the MAQHUE Asia Urbs project (2002 – 2003) in Chiang Mai.

At the administrative level, the main responsibilities of municipalities, as specified in the Municipality Act B.E. 2496 (1953) and the Tambon Administration Organisation Act, B.E. 2537 (1994) are summarized in Appendix 3. Functions of Sub-district Administration Organisations, as identified in the Sub-district Councils and Sub-district Administration Organisations Act B.E. 2542 (1999), are summarized in Appendix 3. However, there is not yet a specific function for local air quality management required by law, as part of their respective roles. However, the management of natural resources and the environment are required by the Tambon (Sub-district) Administration Act (1994). The improvement of natural resources and the environment was included in the 3-year strategic plans of SAOs and municipalities in Chiang Mai. The plan should generally include 5 major components: i) development of basic infrastructure, ii) development of human resources and society, iii) improvement of natural resources and environment, iv) water resource development, and v) development of education, religion and tradition (pers. comm. Ms. Thitirat Intaping, Pong Yang SAO, Chiang Mai; as of January 2005). As part of the decentralization process, the central and regional authorities are required to assist local government organizations in terms of technical support, capacity building, and supervision where necessary. At present, the local government organisations in Chiang Mai have inadequate technical knowledge and capabilities in the area of air quality management. It is crucial for them to be provided with technical assistance through capacity building programmes, including extra funding from central and regional organizations. More detail concerning this issue is included in Chapter 6.

1.5.2 Air Quality Management in Thailand

Air quality management (AQM) is defined as the set of procedures undertaken to maintain air quality at levels that protect human health and provide protection to animals, plants (crops, forests and natural vegetation), ecosystems, materials and aesthetics (such as natural levels of visibility) (Murray, 1997). At a national level, The Air Quality and Noise Management Division, Pollution Control Department (PCD) is responsible for formulating policy planning, action planning, monitoring, and the development of appropriate methods and means to promote and maintain air quality, noise and vibration, as well as establishing appropriate standards for these parameters. The National Air Quality Standards of Thailand are shown in Table 1.3. Other acts containing provisions for motor vehicle emission control include the Land Transport Act 1992; the Motor Vehicle Act 1979; the Traffic Act 1992; and the Liquid Fuel Act 1978. The Government departments responsible for implementing these acts are the Land Transport Department, the Police Department, and the Department of Commercial Registration (Wangwongwatana and Warapetcharayut, 2001). The ambient air quality standard for particulate matter with less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$) is being established by PCD. In order to improve urban air quality, many actions have been implemented, such as improvements in fuel quality (reformulation of automotive gasoline and diesel), adopting the vehicle emission standards of the European Union (EU) for new vehicles, revision of emission standards for in-use vehicles, and implementation of a vehicle inspection and maintenance programme.

At a regional level, the Environment Office Region 1 (EO1) is responsible for improving air quality in 4 provinces in the northern region (Chiang Mai, Chiang Rai, Lamphun and Mae Hong Son). However, the Provincial Office of Natural Resources and Environment (PONRE), Chiang Mai also has direct responsibilities for resolving the air pollution problem in the province. Local air quality management (LAQM) in Chiang Mai should be conducted from a provincial to a local level, which includes all municipalities and sub-district administrative organizations. Existing air quality management (AQM) in Chiang Mai, at the provincial level, is summarized in Chapter 5. Air quality in Chiang Mai is not improving and it is questionable whether the AQM system in Chiang Mai is currently effective. However, LAQM has not yet been established at the local level and, therefore, an investigation was conducted in order to understand current administrative problems (e.g. environmental vision and capacity of SM and SAO officials) (Chapter 6). Since 1996, maximum PM_{10} concentrations (24 hr) have been over 200 $\mu g/m^3$ every year, particularly in winter. There are no effective control measures for open burning (e.g. domestic wastes, rice fields and forests). PCD, CMM and Traffic Police conducted black smoke tests of diesel vehicles. It was found that over 70% of diesel vehicles had black smoke emissions that exceed the standards [40% (full load test) and 50% (free acceleration test), using a filter measuring system]. Traffic congestion has become a daily problem, especially in Chiang Mai Municipal areas. In addition, many factories located in residential areas also contribute to air pollution (CMM, 2002a). Furthermore, respiratory diseases are major causes of illnesses in Chiang Mai. In 1999, 42.7% of Chiang Mai residents were reported to have suffered from respiratory illnesses – drastically increased from 1994 (33%). These illnesses may have resulted from a deterioration in air quality (CMM, 2002a). The implication is that the responsible organizations have failed to manage air quality in Chiang Mai. Therefore, it is important to establish effective local air quality management for the province.

1.5.2.1 National Air Monitoring Network

The monitoring of air quality in Thailand has been conducted since 1983. The ambient air quality monitoring network (established by PCD during 1992-1996) consists of 51 automatic monitoring stations located throughout the country (Table 1.10 and Figure 1.6). The monitored pollutants include CO, NO_x, SO_2, O_3, TSP, PM_{10}, Pb, hydrocarbons and

H_2S. Forty-five of these monitoring stations also have 10m and 30m meteorological masts to measure wind speed/direction, air temperature, humidity, barometric pressure, solar radiation, and precipitation (Wangwongwatana and Warapetcharayut, 2001a). All monitoring stations are automatically operated by remote control from the PCD office in Bangkok. Automatic zero and span checks of gas analyzers in the stations are performed every day. The calibration of the analysers is also conducted manually every 15 days using standard gases of a grade consistent with the US EPA protocols. This bi-weekly calibration is conducted by Sithiporn Associates Co. Ltd. Pollutant concentrations are measured in 'real-time' and the data collected and analysed on an hourly basis by a data acquisition system at each station. Subsequently, the data are transmitted to the central data processing system at PCD through a dial-up telemetric communication system. Annually, an audit of all air monitoring stations within the network is conducted by the Secot Co. Ltd. (pers. comm. Mr. Montri Chutichaisakda).

Table 1.10 Spatial distribution of air quality monitoring stations in Thailand (refer Figure 1.7)

Region	Province	Number of air quality monitoring stations
Bangkok Metropolitan Region (BMR) (28 stations)	Bangkok	17
	Samut Prakarn	5
	Pathumthani	1
	Nonthaburi	2
	Chacheongsao	1
	Samut Sakorn	2
Central (4 stations)	Ayudthaya	1
	Saraburi	2
	Ratchaburi	1
Northern (7 stations)	Chiang Mai	2
	Lampang	4
	Nakorn Sawan	1
Northeastern (2 stations)	Khon Kaen	1
	Nokorn Rachasima	1
Eastern (7 stations)	Chonburi	3
	Rayong	4
Southern (3 station)	Surat Thani	1
	Phuket	1
	Songkhla	1
Total		**51**

Source: Mr. Montri Chutichaisakda (as of December 2005)

Illustrated by Khemmawit Sriyaraj

Figure 1.6 Map of Thailand showing provinces in the Pollution Control Department's Air Quality Monitoring Programme. Refer to Table 1.6 for numbers of monitoring stations in each area.

1.5.2.2 Air Quality Monitoring in Chiang Mai

Within Chiang Mai, there are 2 fixed air monitoring stations – one located at the Yuparaj School, Muang District, for monitoring roadside pollution concentrations, and the other located at the Provincial Hall, Mae Rim District, north of Chiang Mai City (Figure 1.7). The air monitoring instruments at the monitoring stations are listed in Table 1.11. CO, SO_2, NO_2 and O_3 are monitored using non-dispersive infrared detection, UV-fluorescence, chemiluminescence and UV absorption techniques respectively. PM_{10} is detected using US- EPA's β- absorption technique (Table 1.7). The API CO, SO_2, NO_x and O_3 analysers are produced commercially by Teledyne Technologies Incorporated. The operational principles of the analysers are available at the Teledyne website (http://teledyne-api.com/manuals/) (2005). For the PM Beta Gauge automated particle sampler, the producer is now Thermo Environmental Instrument, Inc. The operational methodology is explained by Wedding and Weigland (1991) and US EPA (1999). These monitoring techniques represent the current state-of-the-art for automated air quality monitoring networks (AEAT, 2001). They are recommended by the US-EPA, the UK Department for Transport, and the UK Department of Environment, Food and Rural Affairs (DEFRA) (US EPA, 1999; DEFRA, 2005; Ropkins and Colvile, 2000). For PM_{10} monitoring, both automated Tapered Element Oscillating Microbalance (TEOM) and β –attenuation monitor instruments are widely used, mainly for their reliability and ability to provide near real-time data for public information. Advantages and disadvantages of each sampling technique are summarized in Table 1.12.

Table 1.11 The air monitoring instruments used at Chiang Mai monitoring stations

Parameter	Technique	Instrument Company name/Model
CO	Infrared (IR) Absorption	Teledyne /API M300
SO_2	Ultraviolet Fluorescence	Teledyne /API M100
NO_x	Chemiluminescence	Teledyne /API M200
O_3	Ultraviolet Absorption Photometry	Teledyne /API M400
PM_{10}	β –attenuation	Thermo Environmental Instrument* Beta Gauge10

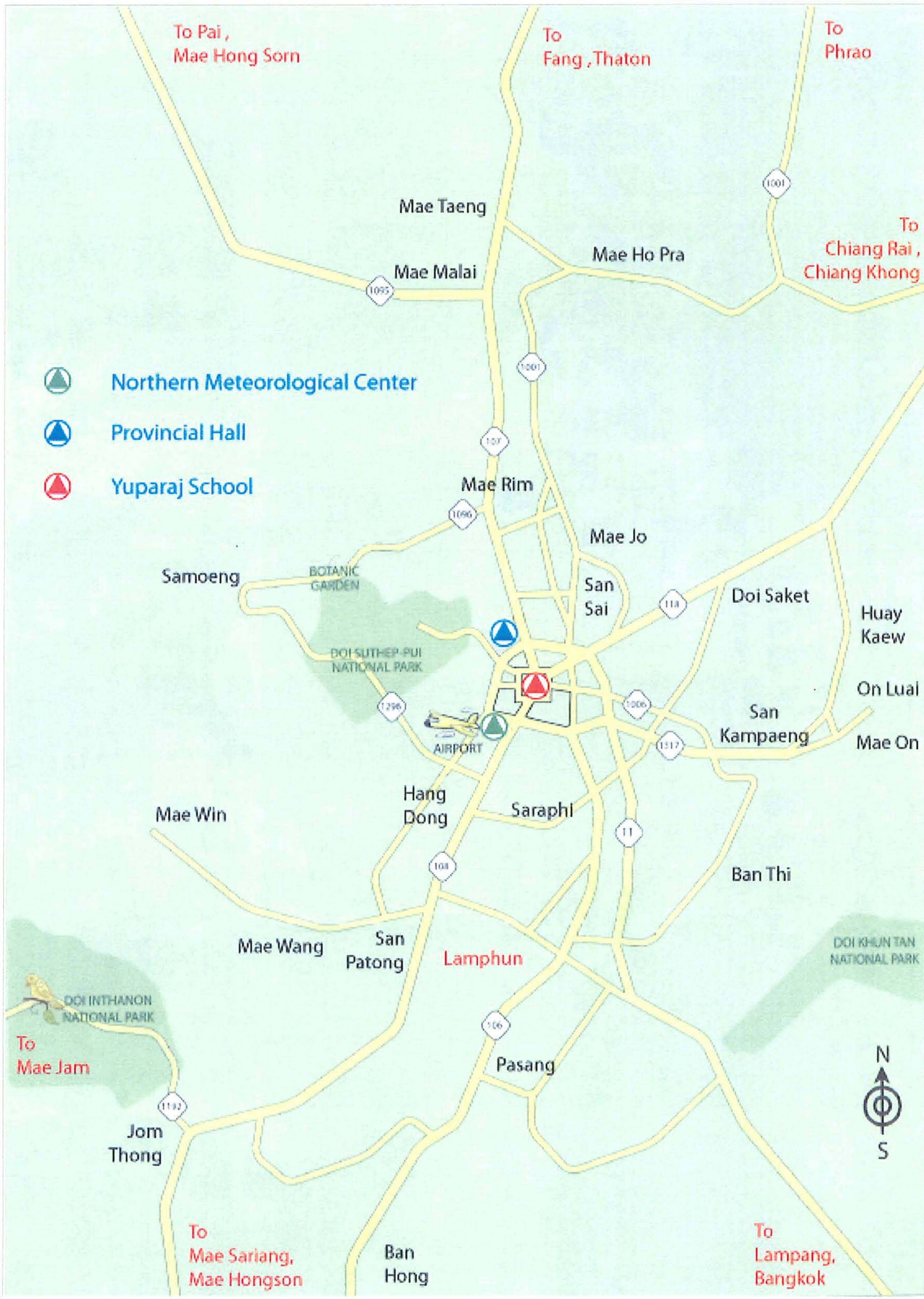
Note: *Formerly Wedding & Associates

Source: Mr. Montri Chutichaisakda (as of November 2005)

<u>Table 1.12</u> Summary of advantages and disadvantages of the Pollution Control Department's sampling techniques

Techniques	Advantages	Disadvantages	Precision/resolution
1. IR Absorption (CO Analyser)	Widely used for routine monitoring. Accuracy is typically high (±8%) (Ropkins and Colvile, 2000).	Expensive; The IR system is subject to interference by humidity and water; Dust and dirt can impair the response (Delphian Detection Technology, 2006).	±0.5% of reading (Teledyne, 1997)
2. UV-Fluorescence (SO_2 Analyser)	Widely used for routine monitoring. Hydrocarbons can interfere with the UV radiation process (AEAT, 2001)	This technique is only practical if the analyte has a short excitation time (e.g. SO_2) but the energy losses (e.g. physical deactivation by air) can cause significant sensitivity reduction (Ropkins and Colvile, 2000). UV radiation could cause eye damage (Maupin, 2003).	±1.0% of reading (AEAT, 2001)
3. Chemiluminescent NO_x Analyser	Widely used for routine monitoring.	High running cost (Ropkins and Colvile, 2000).	±1.0% of reading (AEAT, 2001)
4. UV Absorption (O_3 Analyser)	Widely used for routine monitoring.	UV radiation could cause eye damage (Maupin, 2003).	±1.0% of reading (AEAT, 2001)
5. β –attenuation (PM_{10} Monitor)	Widely used for routine monitoring. Provides real-time data with short time resolution (<1 hr) that can be used for public information (DEFRA, 2005)	If a heated inlet is used, some semi-volatile material may be lost. Unheated samplers may suffer from interference due to the presence of water (DEFRA, 2005)	±3 $\mu g/m^3$ (1-hr averaging time) (US EPA, 1999)

In Chiang Mai, the air monitoring instruments and the QA/QC and auditing systems are relatively good. However, the choice of station locations is questionable since it is not clear that PCD has adequately followed the recommended siting criteria for ambient monitoring stations. For instance, the requirements for a background site (such as the PCD station in the Provincial Hall area) include the following: immediately above the station should be open to the sky with no overhanging trees or buildings; it should be in as open a setting as possible in relation to surrounding buildings; there should be no major sources of pollution within 50m (e.g. car parks); cars/vans/lorries should not be expected to stop with their engines idling within 5 m of the sample inlet; and the site should not be within 10 m of any other road (<10,000 vehicles/day) (AEAT, 2001) . In reality, the surroundings of the station at the Provincial Hall are: a car park immediately next to the station (west); a distance of 10m from the station to the local road (south); approximately 6 m to a tree (8 m high) and 27 m to a 4-storey building (20m high) (west); generally surrounded by mature vegetation (east and south) (Figure 1.8).



Illustrated by Khemmawit Sriyaraj

Figure 1.7 Map of Chiang Mai showing the location of the monitoring station of the Northern Meteorological Center, and the two air monitoring stations at the Provincial Hall and Yuparaj School

For the roadside monitoring station (Yuparaj School), there is a 20m high tree within a distance of 5m to the southwest of the station (Figure 1.9). This tree could have an impact on wind direction and particulate matter may be trapped by its foliage, leading to the under-estimation of PM_{10} concentrations. Mr. Montri Chutichaisakda, PCD, admitted that the siting of existing air monitoring stations in Chiang Mai was not ideal. PCD experienced some difficulties in obtaining permission from the land owners, who normally donated the spaces, which are not used for future construction or development, for monitoring stations. (pers. comm. with Mr. Montri Chutichaisakda). Immediate actions, which could be recommended to the land owners include trimming the branches, or even cutting down some trees that may affect the measurement of pollutant concentrations.

Air quality data from both background and roadside stations in Chiang Mai were used for the validation of the ADMS-Urban model when it was applied to the situation in Chiang Mai. Other meteorological data (e.g. wind speed and direction, cloud cover) that were model input data were routinely monitored by the Northern Meteorological Centre (NMC) (address: Airport Road, Suthep, Muang District, Chiang Mai, Thailand http://www.cmmet.com) (Figure 1.8). NMC was first established in 1942 at the Prince Loyal School. The meteorological station was moved to the present address in 1981. The Thai Meteorology Department (TMD) selected the current site located on a flat plain in Chiang Mai City. In choosing this location, TMD followed the siting standards of the World Meteorological Organisation (WMO), a specialized agency of the United Nations. For example, the site must not be located on top of the hills, near obstructions (tall buildings, trees, cliffs) that affect precipitation and/or wind conditions or near excessive human or animal traffic. The periodic calibration of the instruments is routinely conducted by NMC technicians. Additionally, annual audits are conducted once a year by TMD staff from Bangkok. The main routinely monitored parameters include air temperature, precipitation, cloud cover, and wind speed and direction. The data are recorded and used as representative meteorological conditions for Chiang Mai City. Weather forecasts are made for periods that range from less than 3 hours up to 10 days (pers. comm. with Ms. Suntanee Chaichiangpin, Senior Meteorologist, NMC; as of 2 December 2005).

Figure 1.8 The ambient monitoring station for general air quality located in the Provincial Hall area, Chotana Road, Muang (City) District, Chiang Mai

Figure 1.9 The ambient monitoring station for roadside air quality located in the Yuparaj School area (west of Rachapakinai Road), Muang (City) District, Chiang Mai.

1.5.3 Atmospheric Dispersion Modelling and its Role in Air Quality Management

Atmospheric dispersion modelling is a tool useful for providing information on the origin of pollutants, dispersion processes in the atmosphere, the impact of new pollutant sources and the potential benefits of pollution controls. In contrast, the measurement of ambient air pollutant concentrations often provides little information about the sources of air pollution and air dispersion processes (Williams, 1996). It follows that atmospheric dispersion modelling has become an important tool in many countries to aid the development and implementation of their air quality management programmes (Hickman and Colwill, 1982; Chatterton *et al.*, 2000; DETR, 2000; Team Consulting Engineers, 1997; San José *et al.*, 2000; Kolehmainen *et al.*, 2000; Huang *et al.*, 2002). The underlying principles of such modelling are governed by the physical principles of pollutant dispersion, transport and transformation in the atmosphere – these are treated differently in different models. Mechanical turbulence and atmospheric stability, including mixing heights, and effects from buildings and topography are important in the calculation process. Furthermore, the chemistry of pollutants in the atmosphere must also be accounted for in the models (based on chemical transformation and other removal processes such as dry and wet deposition) (Williams, 1996). Mechanical turbulence is generated as air flows over topographical obstacles on the ground such as crops, hedges, trees, buildings and hills. Turbulence intensity increases with increasing wind speed and surface roughness, but decreases with height above the ground. Due to the heat from solar radiation, convective circulation, driven by buoyancy forces, occurs in the boundary layer. This kind of circulation associated with large eddies can often be seen in the 'looping' plumes from industrial stacks. On the other hand, during calm, clear nights when the earth's surface rapidly cools, there may be little or no generation of mechanical turbulence and circulations of this type may be almost absent. Furthermore, due to variation in solar heating and atmospheric cooling, mixing heights vary throughout the day. At its maximum, the turbulent boundary layer can be about 1000 m in depth. In the evening and night, when the surface is cool, the depth of this layer may be reduced to between 1 – 300 m. Also, both buildings and hills significantly deflect or disturb the dispersion of pollutant plumes – if their dimensions are large in comparison with the plume (Williams, 1996).

The National Institute of Water and Atmospheric Research (NIWA), New Zealand (2004) categorized recent atmospheric models into 3 levels, depending upon their applicability in situations of different complexity. In Table 1.13, a range of recently used models are grouped into the 3 categories, which may be outlined as follows:

i) Gaussian plume models: Use calculations of pollutant concentrations and are based on the Gaussian plume formula, which was derived assuming 'steady-state' conditions. The meteorological conditions, for each hour, are assumed to remain constant during dispersion from source to receptor.

ii) Advanced dispersion models: Depending upon the dispersion of pollutants, the models can be divided into 3 types (particles, puff and grid points). Particle models are applicable when pollutant releases may be represented by a stream of particles (even if the pollutant is a gas), which are transported by the model winds and diffuse randomly. Puff models represent pollutant release as a series of puffs of material, which are subsequently transported by winds. Each puff represents a discrete amount of pollution, whose volume increases due to turbulent mixing. Grid point models represent pollutant distributions as concentrations on a three-dimensional grid of points. However, this method is very similar to the approach commonly used for airshed modelling.

iii) Airshed models: In airshed models, the whole modelling region is horizontally and vertically divided into a series of cells, and the changes in pollutant concentrations are predicted following their movement from one cell to the next. These models can account for chemical transformation because the atmospheric chemical formulations are included. Grid sizes and time scales can vary from large-scale models (with hundreds of kilometers of grid cells and many years) to micro-scale models (with grid cells of a few tens of metres and time steps of a few minutes).

Table 1.13 Types of air modelling programmes, varying from low to high complexity, and their advantages and disadvantages

Complexity Level	Model type	Advantages/Disadvantages
LOW	Gaussian plume models (e.g. ISC, Ausplume);	Widely used, well understood, easy to apply, regulatory used, simple computer resources required; simple meteorological data required/ The models 'break down' in low wind speed and calm meteorological conditions; do not account for turning or rising wind caused by terrain.
	Advanced dispersion models (e.g. TAPM, Calpuff, ADMS-Urban)	Overcome most of the limitations associated with Gaussian plume models/ resources demanding (human. Computer and data); the results may not be more realistic than the Gaussian models.
HIGH	Airshed models (e.g. UAM-V, CALGRID, CMAQ,TAPM)	Highly capable of explaining the effects of all emission sources on a whole areas. Rarely regulatory used, high computing resources required.

Source: The National Institute of Water and Atmospheric Research (NIWA) (2004)

1.5.3.1 Air Quality Modelling Programmes for Chiang Mai

There are a large variety of atmospheric dispersion models available and it is not always an easy task to select an appropriate model for a given piece of research. For any given application, not all models are equally appropriate. In addition to site-specific requirements, factors that must be considered include computer system requirements (outlined below), overall cost of the model and the terms of the licence. This review focuses on those available models for air dispersion in the urban environment that are applicable to use in Chiang Mai.

For Chiang Mai, the following factors need to be considered during the selection of an air quality modelling programme:

- Complex topography with mountainous areas, ranging from 310 m to over 2,500 m above sea level.
- The city is located in the middle of a valley, therefore wind speeds are often very low (<1.0 m/s, sometimes close to 0 m/s) particularly in winter (late November – early March) when the atmospheric pressure is high. Air pollution episodes may occur during this season.
- Precipitation rates are high in the wet season (33 mm-90 mm per day between April – October 2000; source: NMC). Wet deposition should be taken into account in the model calculations.

- Ultraviolet (UV) radiation is strong during the day time in Thailand, located as it is within tropical latitudes. This has an impact upon the rate of photolysis of NO_2 and the formation rate of O_3.
- There are a wide range of air pollution sources – motor vehicles, industry, agricultural burning, forest fires, etc. identified within the Comprehensive Urban Plan (CUP) area of Chiang Mai province (936 km^2).
- There are significant air pollution sources outside the CUP area and Chiang Mai province (e.g. coal burning for electric generation in Lampang; forest fires in other northern provinces), and from even further afield, outside Thailand (e.g. China). These are considered as trans-boundary air pollution.

As mentioned in Section 1.3, in selecting a model, some of the key points mentioned above were not taken into consideration by the senior managers of the MAQHUE project. The ADMS-Urban programme was selected in 2002 to use for modelling air quality in Chiang Mai without consideration of other available air modelling programmes. It was assumed that ADMS-Urban would work as well in Chiang Mai as in the UK and this proved not to be the case. However, ADMS-Urban did prove useful for identifying likely polluted areas ('hot-spots') which, in the case of some pollutants, were likely to exceed national ambient standards. Furthermore, it is considered unlikely that the basic Gaussian plume models can be used in Chiang Mai with any accuracy. Detailed information regarding ADMS-Urban is explained below. Current airshed models that are likely to better address the above atmospheric and topographic conditions in Chiang Mai are reviewed and recommended for future air modelling work.

i) ADMS-Urban Modelling Programme

ADMS-Urban is a PC-based, advanced model of the dispersion of pollutants that are released from multiple industrial, domestic and road traffic sources in urban areas (CERC, 2001). It is widely used for air quality management by local governments in the UK e.g. Manchester, Nottingham City, and some London Boroughs (e.g. Barnet, Camden, Croydon, Islington). It has also been used by some Scottish and Welsh Councils, which include Cardiff, Neath Port Talbot and Glasgow. In addition, there are some studies involving the use of ADMS-Urban in China and Hong Kong (McHugh *et al.* 2005; Huang *et al.*, 2002). CERC claimed that ADMS-Urban is different from other urban air dispersion models because it applies up-to-date physics using parameterisations of the atmospheric boundary layer structure based on the Monin-Obukhov length (L_{MO}) and the boundary layer height, not Pasquill-Gifford stability parameters which imprecisely characterise the boundary layer (CERC, 2001). L_{MO} gives a measure of the relative importance of buoyancy, generated by heating of the ground, and mechanical mixing generated by the frictional effect of the earth's surface. It represents the depth of the boundary layer within which mechanical mixing is the dominant form of turbulence generation (CERC, 2002). The Monin-Obukhov length can be defined as:

$$L_{MO} = \frac{-u_*^3}{B},$$

Where u_* is the friction velocity at the earth's surface (m/s), and B is the buoyancy flux, which will increase with increasing surface heat flux (CERC, 2001). B is defined as:

$B = (k.g.F(\Theta_0)) / (p.C_p.T_0)$, where

k is Von Karman constant (= 0.4),

g is the acceleration due to gravity (9.81 m/s^2),

$F(\Theta_0)$ is the surface sensible heat flux (W/m^2),

p is the air density (g/m^3)

Cp is the specific heat capacity (J/kg/K)

T_0 is the surface temperature (K)

The Pasquill-Gifford stability (the state of the boundary layer) is categorised into 7 classes ranging from A to G where A, D and G are associated with the most convective (unstable) conditions and the most stable conditions respectively. Whereas the L_{MO} approach uses a continuous scale, and the variation of boundary layer parameters with height is accounted for by the L_{MO} characterization. However, ADMS-Urban parameterises the variation of turbulence with different heights within the atmospheric boundary layer. In ADMS-Urban, three meteorological conditions are defined – stable ($h/L_{MO} \geq 1$; h = boundary layer height), neutral ($-0.3 \leq h/L_{MO} < 1$) and convective ($h/L_{MO} < -0.3$) (CERC, 2001). In addition, the model uses a skewed-Gaussian distribution to determine the vertical variation of pollutant concentrations in the plume (Owen *et al.*, 2000).

For this study, the ADMS-Urban model was used in conjunction with the ArcView GIS *version 3.2a* and ArcView Spatial Analyst *version 2.0a* programmes, to create outputs such as contour plots of concentrations of pollutants and produce pollution maps. ADMS-Urban is a PC-based model, therefore, it is easy to set up, unlike a UNIX workstation plus a PC, for example, the Indic Airviro model. Microsoft Office Pro 97 or 2000 software is required to set up the ADMS-Urban programme. Also, numerical outputs calculated by the model are predicted concentrations of pollutants that include percentiles and rolling averages.

However, ADMS-Urban has some limitations. It requires a large body of input data, which is time-consuming to collate. It can handle only a limited number of sources and run times are long, particularly when hourly meteorological data are used together with emissions rates from several sources. It showed poor agreement with monitored concentrations on an hour-by-hour basis, although reasonable agreement is possible with longer term statistics (DEFRA, 2000). In addition, the model may not be ideal to predict pollutant concentrations in calm meteorological conditions that often lead to air pollution episodes (Leuzzi, 2002; DEFRA, 2000). DEFRA (2000) also reported that ADMS-Urban under-predicted the concentrations of total oxides of nitrogen when used for air dispersion modelling at Avonmouth, Bristol, UK. In contrast, over-estimates of predicted concentrations were found when wind speeds were less than 2 m/s. CERC (2001) recommended that the model should not be used when the wind speed is less than 1 m/s.

Huang *et al.* (2002) used the ADMS-Urban programme to calculate concentrations of NO_x, NO_2, O_3 and respirable suspended particulates (RSP or PM_{10}) in Hong Kong urban areas (Tsim Sha Tsui) where air pollution problems are mainly caused by motor vehicles, particularly diesel vehicles such as trucks, buses and light buses. The ADMS-Urban model was run for the whole year of 2000. The predicted RSP (monthly average) concentrations were slightly lower than the concentrations indicated by air quality monitored data. The NO_2 results produced by the model were reasonably accurate in comparison to the monitored data, but NO_x concentrations were 20% overestimated – especially in summer. For O_3, (due to lack of input data for VOC emissions), the concentrations determined by the chemical reaction scheme of the model were 50% lower than the monitored data. Seasonal variations of pollutants were found from both the model and monitoring stations.

Owen *et al.* (2000) compared the predictions of ADMS-Urban for NO_x and NO_2 with the 1995 monitored data in London. It was found that there was a reasonable agreement during the summer period; however, the model significantly under-predicted the concentrations of NO_x in winter, especially during cold, stable weather conditions. Carruthers *et al.* (2002), in a comparison between ADMS-Urban predictions and monitoring data, showed that the ADMS-Urban generally performed well in the UK especially for PM_{10} and NO_2. It was also pointed out that the concentrations of PM_{10} and NO_2 remained a problem in large urban areas and more especially in London. The ADMS-Urban was applied to emissions from industrial sources in Clitheroe, the Mersey Estuary and Avonmouth, UK (DEFRA, 2000). The agreement between SO_2 concentrations from the model and monitored concentrations over the longer term (months) was relatively good, but the agreement was poor over shorter time-spans (hours).

According to the European Topic Centre on Air and Climate Change (2003), a major technical limitation of ADMS-Urban is that it decreases in accuracy with calm wind and rapidly changing weather conditions. These limitations are similar to those of the Industrial Source Complex (ISC) and AERMOD models. None of these can adequately account for meteorological conditions, which are calm and/or dominated by mountain and valley winds because of their steady-state formulation (assuming uniform meteorological conditions). Additionally, Gaussian-plume models are not recommended for use in the situations of complex terrain boundaries (NIWA, 2004). Although the ADMS-Urban parameterization using h and L_{MO} was claimed to overcome the limitations of pollutant dispersion over complex terrain, the model did not appear to cope well with the complex terrain in Chiang Mai. In conclusion, it is considered that ADMS-Urban should not have been recommended for Chiang Mai due to the combination of low wind speeds (particularly in winter) and complex terrain in the province. A more detailed discussion of the limitations of ADMS-Urban for use in Chiang Mai is presented in Chapter 2.

ii) Airshed Modelling Programmes – Recommendation for Air Quality Modelling in Chiang Mai

Given that there appear to be problems with ADMS-Urban in its application to Chiang Mai conditions, other models should be considered. Four airshed models, mentioned in the Good Practice Guide for Atmospheric Dispersion Modelling (NIWA, 2004), include UAM-V (Urban Airshed Model – variable grid), CALGRID, TAPM, and Models-3/CMAQ (the Models-3 Community Multi-scale Air Quality). It is noted from the literature review, there have not been many applications of airshed models in Asian countries. Information regarding each model is summarised in Table 1.14.

CALGRID, a photochemical air quality model, has been widely used in the U.S. (Jiang *et al.*, 2003, Villasenor *et al.*, 2001), Canada (Jiang *et al.*, 1997) and Europe (Guariso *et al.*, 2004; Pilinis *et al.*, 1993) but has not been much used in Asian countries. UAM-V has been used for predicting ozone and its precursors, particularly in the U.S. (Hanna and Davis, 2002; Streets *et al.*, 2001; Hanna *et al.*, 2001 and Hanna *et al.* 1996). In Korea, Oh *et al.* (2006) recently applied UAM-V in conjunction with MM5, a meteorological model to study the effects of the late sea breeze on O_3 distributions in the Busan Metropolitan area. MM5/UAM-V performed well in the study. It also appeared to work well under low wind speed conditions. However, the uncertainties in O_3 predictions, using UAM-V, depend upon the NO_2 photolysis rate, wind speed and direction, humidity, cloud cover and biogenic VOC emission (Hanna *et al.*, 2001). TAPM is applied for predicting both meteorology (e.g. wind speed) and pollutant concentrations (e.g. PM) and has been used mostly in Australia and New Zealand. (Wilson and Zawar-Reza, 2006; Hurley *et al.*, 2005; Zawar-Reza *et al.*, 2005; Hurley *et al.*, 2003; Hurley *et al.*, 2001).

Table 1.14 Information of four airshed models, recommended by the National Institute of Water and Atmospheric Research (NIWA), New Zealand

Airshed model	Developer	Model information
UAM-V	Systems Applications International (SAI)	UAM-V performs reasonably well, but is not user-friendly and requires a great deal of effort to run. It has numerous modules and a complex structure. It is freely available through the US EPA website www.epa.gov/scram001 and at http://www.uamv.com/.
CALGRID	EarthTech Inc.	CALGRID is more user-friendly than UAM-V. It is easier to install and run but still need a considerable effort to obtain the appropriate emissions inventory files. It also links to CALMET model that produces a realistic meteorological file. CALGRID is freely available from either EarthTech or the California Air Resources Board website (http://www.arb.ca.gov/eos/soft.html#calgrid).
TAPM	CSIRO Marine and Atmospheric Research, Australia	TAPM can consider more complex chemical transformation mechanisms, when coupled with the CSIRO chemical transport model. TAPM can also be applied to predict inter-seasonal and inter-annual variations in photochemical smog concentration.
Models-3/CMAQ	US EPA	The Models-3 photochemical-aerosol modelling system is a complex, multi-scale modelling system comprising an emissions inventory, prognostic meteorological modelling and chemical transport-transformation modelling sub-systems. The Community Multi-scale Air Quality (CMAQ) is a main component of the system that takes account of the processes of pollutant transport, chemical transformation, and wet and dry deposition for a variety of primary and secondary gaseous and aerosol species.

Source: NIWA (2004)

An airshed model which has been widely used in Asia is the Models-3/CMAQ system that allows the study of the effects of air pollutant emissions over spatial scales ranging from local to trans-national. The system can be used for both urban and regional scale air quality modelling of tropospheric ozone, acid deposition, visibility and particulate matter ($PM_{2.5}$ and PM_{10}) (Ching and Byun, 1999). Its temporal resolution is sufficient to allow episodic air quality events to be studied. Models-3/CMAQ has a unique framework and design that enables scientists and regulators to build their own modelling systems to suit their needs. They can either directly use the model or incorporate their own modelling systems to work within the existing framework. Models-3 was referred to as a 'one atmosphere' model, which means that all relevant processes in a wide range of temporal and spatial scales are calculated simultaneously in a single model run (Ching and Byun, 1999). Fu *et al.* (2004) applied the Models-3/CMAQ to national and regional air quality modelling in China. The model proved useful for the prediction of $PM_{2.5}$ and O_3 episodes and visibility, but comparison of results with monitored data showed a general underestimation of levels in relation to O_3. However, the input data used for these trials were from the Asian emissions inventory (the NASA TRACE-P database), which may not be sufficiently accurate. Therefore, this inventory was replaced by a local emission inventory for China in later calculations. As yet, the final results of the modified modelling have not been presented for publication; but they are expected to provide more accurate predictions. Recently, Kim *et al.* (in press) applied Models-3/CMAQ to investigate NH_3 emissions and particulate formation (mainly NO_4^+ - NO_3^-) in East Asia. The predicted gas-phase NH_3 concentrations were found to be overestimated by the model by 1.2–3.8 times. Therefore, it was recommended that NH_3 emission fields should be reduced by approximately 20-75% in future modeling studies for East Asia. Sakurai *et al.* (2003) used Models-3/CMAQ in conjunction with the Mesoscale Model, version 5 (MM5) for predicting high NH_3 concentrations during night time in Kagurazaka, Tokyo. The model performed well in this study, resulting in good agreement between predicted and observed concentrations. Rather than applying only Models-3/CMAQ alone, the model may perform better when it is used in conjunction with MM5. MM5 is designed to simulate or predict mesoscale atmospheric circulation. This model can be adapted to use with other modelling programmes such as Models-3/CMAQ and UAM-V. The model has been developed by the National Centre for Atmospheric Research (NCAR), Pennsylvania State University (PSU) (UCAR, 2006).

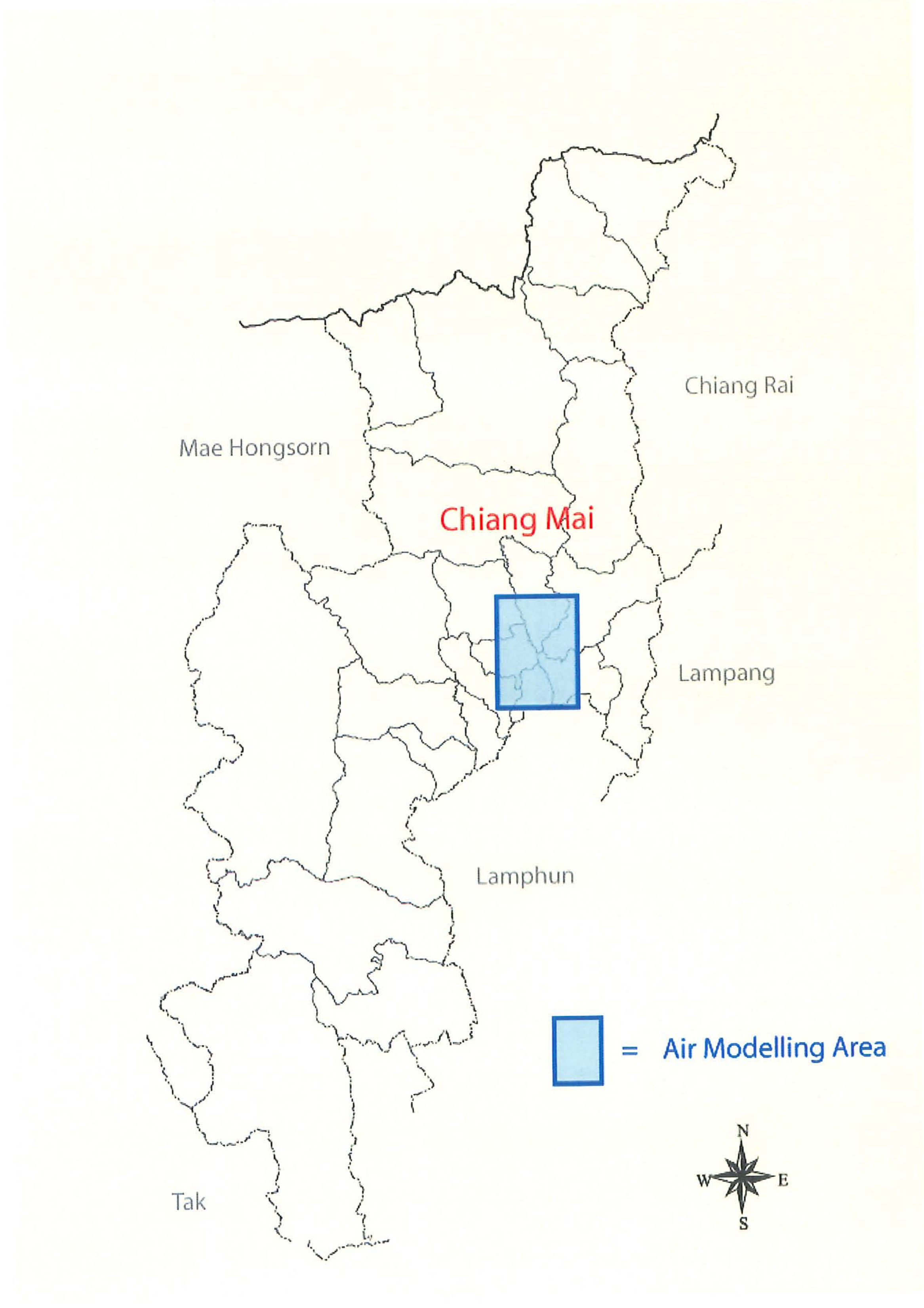
CHAPTER 2

MODELLING AIR QUALITY IN CHIANG MAI

2.1 Introduction

A key objective of the PhD research programme was to compare air quality data for Chiang Mai with national air quality standards (Section 1.4.2), and to identify areas that are likely to be significantly polluted (hot-spots) using the ADMS-Urban dispersion modelling system. Modelling air quality in Chiang Mai, Thailand was carried out in three phases: during February-March 2003 (Phase I); August-September 2003 (Phase II) and February 2005-April 2005 (Phase III) using the Atmospheric Dispersion Modelling System (ADMS-Urban) programme *versions 1.6 and 2.0.* The main objectives of the modelling exercise were to indicate likely polluted sites in Chiang Mai major urban districts, and parts of its suburban districts and compare pollutant concentrations (as calculated by ADMS-Urban) with those concentrations measured in Chiang Mai at two monitoring stations (ambient and roadside stations) and by a portable MiniVol™ sampler (for PM_{10} monitoring). For this study, the modelling area was approximately 936 km^2 and corresponds to the area covered by the Chiang Mai Comprehensive Urban Plan. This plan has been produced by and is the responsibility of, the Chiang Mai Office of Public Works and Town and Country Planning (CMOPT) (Figure 2.1).

Within Chiang Mai Province (20,107.06 km^2), air pollution monitoring stations are few; therefore, air quality modelling is potentially an important planning and pollution management aid. The putative significantly polluted areas (hereafter referred to as 'hot-spots') identified by ADMS-Urban were used during site selection for both the quality of life questionnaire survey conducted in urban and suburban areas (Chapter 3) and the study of the prevalence of respiratory diseases and allergies among school children (Chapter 4). In this study, a 'hot-spot' was defined as an area where maximum concentrations of a pollutant of interest, as predicted by ADMS-Urban, exceeded the national standards (Table 1.3). For example, Saraphi Junction is a PM_{10} 'hot-spot' due to ADMS-Urban having predicted maximum PM_{10} concentrations of over 120 $\mu g/m^3$. However, in Phase I modelling work, when background concentrations for most pollutants were not input into the model, most of the predicted maximum concentrations were relatively lower than the national standards. Therefore, during that phase, the 'hot-spot' areas were based upon the upper end of the range of concentrations for each pollutant (PM_{10} 50-60 $\mu g/m^3$; NO_2 90-200 ppb; NO_x 240-600 ppb; CO 2-5 ppm; SO_2 0.55-0.65 ppb; VOC 60-260 ppb).



Illustrated by Khemmawit Sriyaraj

Figure 2.1 Map of Chiang Mai showing the province as a whole and the location of the area used for this air modelling study

2.2 Uncertainties and Limitations

The ADMS-Urban air modelling programme is theoretically not appropriate for Chiang Mai conditions due to its very low ambient wind speeds and the complex topography in this region (see Figure 2.2 and Section 1.5.3.1). Other uncertainties and limitations were also found when the model was applied to Chiang Mai data and are addressed as follows;

Source: Chiang Mai Municipality (2002a)

Figure 2.2 A map illustrating the complex topography of the Northern region of Thailand. The city centers of Chiang Mai and Lamphun Provinces are located in a valley aligned roughly along a north-south axis.

2.2.1 Emissions

The emission rate of each pollutant, at each point, area and road source, is one of the critical inputs required by ADMS-Urban. In 2001, an Emissions Inventory was developed by the Chiang Mai Municipality (CMM) and the Pollution Control Department (PCD), with the assistance of the Maryland Department of Environment (MDE), US-Environment Protection Agency (US EPA) and US-Asia Environmental Partnership (US AEP) (CMM, 2002b). This inventory included emission rates (e.g. tons/year) from point, area and mobile sources as listed in Table 2.1. The emission rates, and other information, produced by the MDE study were used for dispersion modelling. The ADMS-Urban model requires the entered emission rates to be in terms of units per second (e.g., g/s, $g/m^2/s$, g/km/s), therefore, for each source and each pollutant, this input data was derived from the annual emission rates provided by the MDE study.

Table 2.1 List of sources emitting air pollutants in Chiang Mai as part of the MDE project

Source type	Source	Pollutants studied
Point source	- 6 factories	PM, NOx, SO_2, CO, VOC
	- 5 hospital waste incinerators	PM, NO_2, SO_2, CO, TOC, HC
	- 14 crematoria	PM, NO_2, SO_2, CO, TOC
Area source	- 2 airports	PM, NOx, SO_X, CO, HC
	- Petrol stations in CM municipality	VOC
	- Residential & commercial	PM, NOx, SO_X, CO, VOC
	- Agricultural burning	PM,CO, VOC, NMHC
	- 1 railway station	NOx, CO, HC
	- Forest fires	PM, NOx, CO, VOC
	- Domestic waste burning in municipality area	PM, NOx, SO_X, CO, VOC
Mobile source	- 30 main roads	PM, NOx, SO_X, CO, VOC, HC
	- 1 railway line	PM, NOx, SO_X, CO, VOC, HC

However, the MDE's emissions inventory is not adequate for some sources - especially for road sources. Consequently, the detailed road data set for Chiang Mai that was input into the model was taken from another source - the project on Traffic and Transport Planning in Chiang Mai (OCMRT, 2002), conducted by the Office of the Commission for the Management of Road Traffic (OCMRT) and Chiang Mai University (CMU) in 2002. But even this data set also presented problems as road-specific data were not collected in the OCMRT study. Therefore, the 1999 UK Design Manual for Roads and Bridges (DMRB) database of traffic emissions was applied. The DMRB database contains emission factors depending on vehicle category (light and heavy duty vehicles), average speed and traffic count, for NO_x, CO, PM_{10} and VOC. The current data set in ADMS-Urban *version 1.6* is DMRB 1999, which is the default option in the model. By selecting the DMRB 1999 option, an emission rate for each road source is automatically calculated by ADMS-Urban, providing that a vehicle count per hour and an average vehicle speed are entered into the model.

The DMRB emission factors were designed for vehicle fleets and road types in the UK [UK Highway Agency (1999 and 2003), cited by CERC (2003a)]. DMRB characterised vehicle fleets into 2 groups – light duty vehicles and heavy duty vehicles. These are different to the vehicle fleets in Chiang Mai, are 4 types – gasoline cars, light duty diesel vehicles, heavy duty diesel vehicles, and motorcycles (CMM, 2002b). To apply DMRB calculations to Chiang Mai traffic data may under-estimate pollutant emissions because most of the motor vehicles in Chiang Mai were much older than those in the UK. For example, in 2001, PCD introduced Euro I motor standards to Thailand (pers. comm. Mr. Panya Warapetchrayut) while the UK introduced Euro III (UK Commission for Integrated Transport, 2001). At present, old diesel vehicles, classified into Pre-Euro I to Euro I standards, are still used in Chiang Mai (pers. comm. Mr. Panya Warapetchrayut). However, CERC (2003a) recommended to select the DMRB 2003 (default option) except for historic comparisons or re-running old model runs. In this modelling work, DMRB 1999 was used because there was no updated DMRB 2003 option in ADMS-Urban version 1.6 when the later version (2.0) was installed, DMRB 1999 remained the chosen option in order to maintain comparability among all three phases of model runs. Moreover, in this modelling work, the number of heavy duty diesel vehicles was input into the model as DMRB heavy duty vehicles, and the rest of the vehicles were input as light duty vehicles.

PCD's MOBILE 5a.2 (Thai version) model, introduced by PCD in 2001, for calculating pollutant emissions from traffic sources could be used in this respect because it has input options for a range of vehicle fleets suitable for local conditions. This model was developed from the US EPA MOBILE 5 emission factor model and was customized to conditions in Thailand by taking account of local factors such as characterization of the vehicle fleet, fuel characteristics, average speed and air temperature (Wangwongwatana and Warapetchrayut, 2001a). Furthermore, the Mobile 5a.2 model was used by the PCD and CMM for the Maryland Department of Environment funded project for air pollution prevention and control in Chiang Mai Municipality (MDE project), undertaken during

2001-2002. However, this alternative model (or others) was not considered by the project partners of the MAQHUE project.

There have been no local emission factors for various air polluting activities, from industrial and area sources, developed specifically for Chiang Mai. Emission rates for industrial activities and area sources used (from the MDE project) are the AP-42 emission factors. These were developed by the US EPA (under US conditions), but may not accurately represent local conditions in Chiang Mai because of differences in, for example, industrial processes, fuel characteristics and quality, air temperatures and fuel burning temperatures. Furthermore, even though location (x, y coordinates), stack height and diameter data given by each factory were confirmed by re-measurement by CMOPT staff, the lack of data for most of the factories in the province (in 2001 there were 2,346 factories in total but data from only 30 were available for this modelling work) may have caused significant under-estimation of pollutant concentrations from industrial point sources. Chiang Mai Provincial Industry Office estimated that 224 factories (out of 2,346 factories) were major polluters due to their processes (e.g. burning fuels for boilers) (Waiyawajamai, 2003). However, the office has not yet developed an industrial emissions inventory for Chiang Mai (as of November 2005).

2.2.2 ADMS-Urban Chemistry Module

The ADMS-Urban chemistry module consists of the NO_x-NO_2 Correlation (Derwent-Middleton Correlation) and Chemical Reaction Scheme. In the Derwent-Middleton correlation, NO_2 concentrations are calculated from input NO_x emissions. The concentration of NO_2 is calculated using the following function where concentrations are hourly-averaged values in ppb (CERC, 2003):

$$[NO_2] = 2.166 - (1.236 - 3.348A + 1.933A^2 - 0.326A^3)\ [NO_x]$$

where $A = \log_{10}([NO_x])$. However, the equation was developed by Derwent and Middleton (1996) based upon monitoring data collected under UK meteorological conditions and it is unlikely to be truly representative of Chiang Mai meteorological conditions and the local conversion rates of NO_x to NO_2.

Within the Chemical Reaction Scheme, both NO_x chemistry (through the Generic Reaction Set or GRS) and sulphate chemistry are taken in to account. A series of chemical reactions that involves NO, NO_2, VOCs and O_3 are included in the GRS. A conversion reaction from NO to NO_2 (2NO+O_2 □ 2NO_2) is also included in the GRS chemistry scheme (CERC, 2003a). For sulphate chemistry, SO_2 is oxidized to SO_3 that reacts immediately with water to form sulphuric acid, which then reacts with ammonia in the atmosphere to form ammonium sulphate. Ammonium sulphate is a solid form and therefore adds to PM_{10} concentrations (CERC, 2003a). The Chemical Reaction Scheme itself is likely to be relatively well-suited to Chiang Mai conditions because it involves important general chemical reactions that include NOx-NO_2 chemistry as well as VOCs and O_3 in photochemical conditions.

2.2.3 Air Monitoring Data

As mentioned in Section 1.5.2.2, there were some siting problems with the locations of the two PCD air monitoring stations in Chiang Mai (e.g. surrounded by mature vegetation, next to car park, etc.) and this may have led to either under- or over-estimation of pollutant concentrations. For ADMS-Urban input, CERC suggested background pollutant concentrations should come from either sub-urban or rural areas (pers. comm. Dr. Patricia Gilmour). DEFRA recommended that background monitoring stations should be distanced from major sources by more than 50 meters and, therefore, broadly represent background conditions (DEFRA, 2003). Consequently, the monthly and annual average concentrations from the ambient monitoring station at Provincial Hall were not used as background concentration input for ADMS-Urban (see Section 1.5.2.2).

Theoretically, the pollutant concentrations from this monitoring station should not also be used as background concentrations. However, because there were no other available monitored data, the minimum concentration of each pollutant (in 2001) monitored at Provincial Hall was used as a background concentration, based on the assumption that the lowest concentration of each pollutant was as low as general background concentrations. However, PCD later suggested that background SO_2 concentrations can be as low as zero in Chiang Mai because SO_2 concentrations in non-polluted atmosphere are negligible (pers. comm., Mr. Montri Chutichaisakda). Zero ppb SO_2 was used in Phase III of the modelling. The absence of data on the true background concentrations of air pollutants in Chiang Mai is also a major concern for this modelling exercise. Additional monitoring, using mobile air quality monitoring stations, or (for PM_{10}) portable monitors such as_MiniVol samplers, should be undertaken to establish more typical values for the background levels in Chiang Mai. Background concentrations (e.g. PM_{10}) should be a representation of the incoming pollutant concentrations brought in by the prevailing wind. Thus the background monitoring sites should be upwind of Chiang Mai (pers. comm., Prof. J Longhurst). Influenced by the topography, prevailing winds flow though a long Chiang Mai-Lamphun valley aligned roughly along a north-south axis (Figure 2.2). In winter, when the prevailing wind direction is NNW (Figure 2.3), the background monitoring site should be located in the north or northwest of Chiang Mai such as in Mae Rim District, outskirts of Muang (City) District. In contrast, in the wet season when the prevailing wind is from the SSE direction (Figure 2.4), the background monitoring site could be located in Ban Thi, Lamphun Province (outskirts of Saraphi District) (Figure 1.8). To locate the site in Saraphi District in the wet season is not recommended due to this area being a major longan fruit plantation area where the burning of longan branches and leaves is normal practice during the end of the harvesting season (August) (pers. comm., Ms. Peungpit Ngamsai, CMOPT). For model validation, the predicted outputs were compared with data from the two PCD ambient stations located in the Provincial Hall area, and Yuparaj School (Figure 1.8).

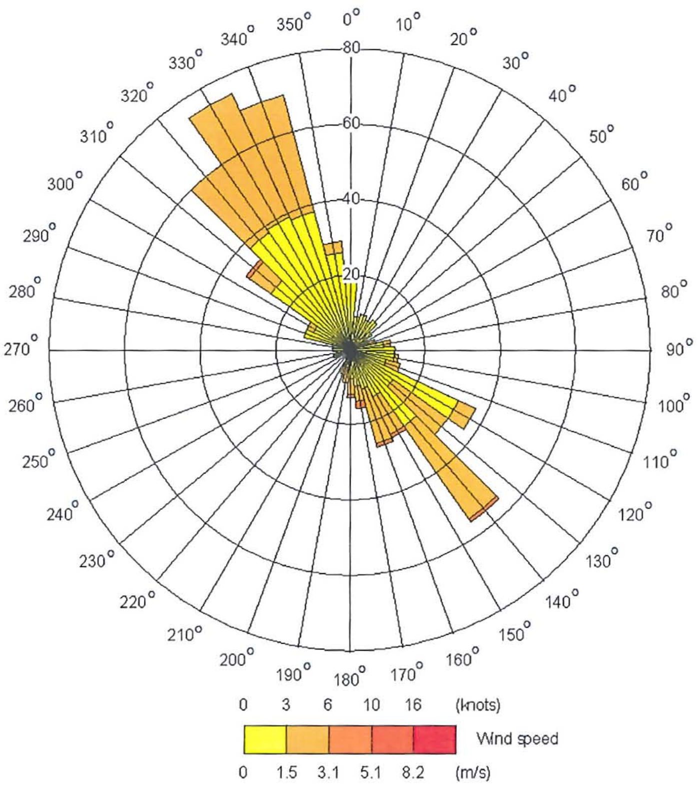


Figure 2.3 Wind rose for February 2001 (winter) showing the prevailing wind direction and strength in Chiang Mai during the Northeast monsoon. Graph produced by ADMS-Urban using hourly data from the Pollution Control Department's ambient air monitoring site at Chiang Mai Provincial Hall.

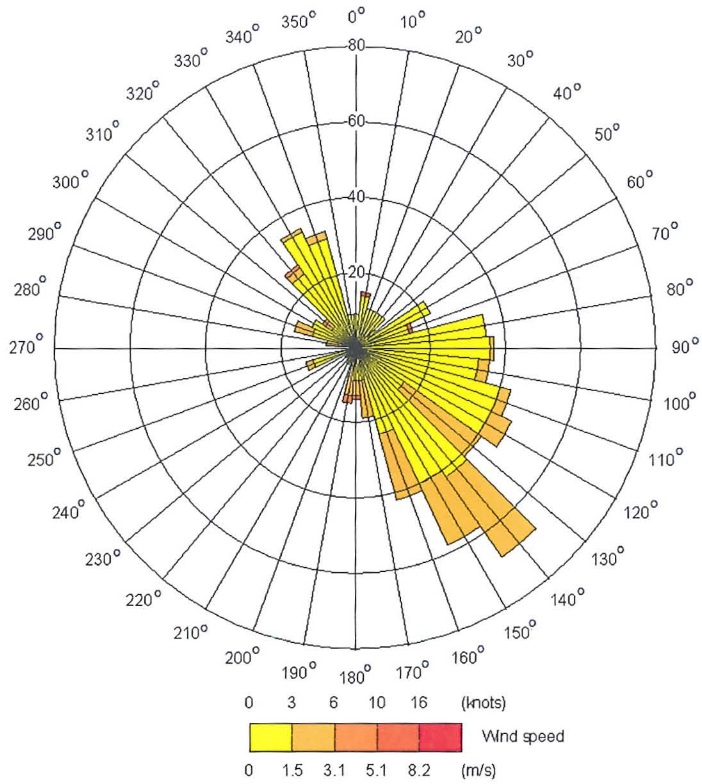


Figure 2.4 Wind rose for August 2001 (wet season) showing the Southeasterly direction and strength of the prevailing wind in Chiang Mai. Graph produced by ADMS-Urban using hourly data from the Pollution Control Department's ambient air monitoring site at Chiang Mai Provincial Hall.

2.2.4 Prediction of Pollutant Concentrations during Air Pollution Episodes

A model is a simplified picture of reality and it does not contain all the features of the real system (NIWA, 2004). Generally speaking, atmospheric dispersion models may not perform well enough to predict atmospheric pollution episodes. In this study, ADMS-Urban was used to predict PM_{10} concentrations during winter air pollution episodes in Chiang Mai during February-March 2004. The results of model validation with MiniVol monitoring data showed ADMS-Urban under-estimating actual PM_{10} concentrations by a factor of 2.5-4.5 (see Table 2.10). The complex set of conditions which bring about an air pollution episode is likely to be beyond the capacities of dispersion models such as ADMS-Urban to predict (e.g. very low wind speed during an air pollution episode).

2.2.5 ADMS-Urban Complex Terrain Module

In order to take account of the complex topography of Chiang Mai, the Complex Terrain module in ADMS-Urban should be selected, requiring the inclusion of a terrain file that contains x, y and z (terrain elevation or height) coordinates. During a model run choosing the Complex Terrain module, the terrain data are interpolated onto the local grid and mean air flow, shear stress and turbulence, mean streamline through source and pollutant concentration distribution are also calculated (CERC, 2003a). However, the module does not cope well when very high slopes exist (greater than 1 in 2) since reverse flows will occur locally near the surface and the dispersion calculations will fail if the plume centerline passes through such regions (CERC, 2003a).

Due to the combination of very low wind speeds and mountainous topography in Chiang Mai, the model runs using the Complex Terrain module failed. Therefore, the air modelling results presented in Chapter 2 are for the runs that did not include the terrain file as an input.

2.3 Methodology

The modelling methodology employed for the estimation of air quality in Chiang Mai using ADMS-Urban is summarised as follows:

(i) ArcView GIS *version 3.2a*, ArcView Spatial Analyst *version 2.0a* software, and ADMS-Urban *version 1.6* were installed on a personal computer. ADMS-Urban *version 2.0* was later installed.

(ii) The required input data for road traffic and for point and area sources of air pollution (PM_{10}, NO_2, SO_2 and CO) were collected, and then collated into the appropriate format and units for ADMS-Urban (Appendix4). Table 2.2 shows a list of the data used for this study.

(iii) The ADMS model was run assuming different scenarios: For different atmospheric chemistry schemes (Derwent-Middleton correlation, and Generic Reaction Scheme); for different months (February and August); using traffic data that either included or did not include data on diurnal traffic variations (Figure 2.5). ADMS-Urban can take account of emissions that vary with the time of day (e.g. rush hours or night time) or day of the week (e.g. weekdays and weekends) (CERC, 2003a). In Phases II and III modelling work, in order to take account of variations of motor vehicle emissions in Chiang Mai, diurnal traffic variation proportional factors were included into the model (more detail in Section 2.2.1.1).

Table 2.2 List of data inputs for the ADMS-Urban model

Data	Source of data	Type of data	Note
1. Pollution source			
1.1 Traffic source			
1.1.1 Vehicle count	OCMRT (2002)	Secondary	
1.1.2 Average speed	OCMRT (2002)	Secondary	
1.1.3 Emission rate	DMRB 1999	Secondary	Calculated by ADMS-Urban
1.1.4 Canyon height	CMOPT	Raw	Fieldwork
1.1.5 Elevation of roads and bridges	KS	Raw	Field work. KS estimated that all road elevation in Chiang Mai is 1 m high, after measuring some roads. KS measured height of bridges in CM with the assistance of 2 CMOPT staff.
1.1.6 Road width	CMOPT	Raw	Field work
1.2 Industrial source			
1.2.1 Grid references	CMOPT	Raw	Field work
1.2.2 Stack height/diameter	CMOPT	Raw	Information given by each factory
1.2.3 Exit velocity			Estimated value based on PCD
1.2.4 Type/amount of fuel used	CMOPT	Raw	Given by each factory
1.2.5 Emission rates	KS	Raw	Calculated by KS based on PCD's MDE study report which AP-42 emission factors were used.
1.3 Area source			
1.3.1 Location of airports	CMOPT	Secondary	From CMOPT Chiang Mai maps
1.3.2 Location of train station	CMOPT	Secondary	From CMOPT Chiang Mai maps
1.3.3 Location of forest fires	KS and OPTCP	Secondary	The estimations are based on forest fire data from Chiang Mai Office of Forestry
1.3.4 Location of rice fields and orchards	CMOPT	Secondary	Electronic aerial Chiang Mai maps
1.3.5 Rubbish burning, petrol stations and commercial and residential areas	PCD and CMM	Secondary	MDE project's report
1.3.6 Emission rates of area source	PCD and CMM	Secondary	Based on Emissions Inventory developed by PCD and CMM as part of MDE project
2. Background concentrations of pollutants	PCD	Secondary	Annual averages monitored by PCD ambient monitoring station (2001).
3. Ambient and roadside monitored concentrations of different pollutants	PCD	Secondary	PCD' automatic monitoring stations
4. 24-hr PM_{10} concentrations (Minivol)	Department of Chemistry, CMU	Raw	Field work with KS.
5. Base map of Chiang Mai	CMOPT	Secondary	In ArcView format
6. Meteorological data	NMC and PCD	Secondary	Electronic data from PCD ambient monitoring station and NMC station (2001)

Note: DMRB = Design Manual for Roads and Bridges (UK Highway Agency); CMOPT = Chiang Mai Office of Public Works and Town and Country Planning, Thailand; OCMRT = Office of the Commission for the Management of Road Traffic, Thailand; KS = Kanyawat Sriyaraj; CMM = Chiang Mai Municipality; CMU = Chiang Mai University; NMC = Northern Meteorological Center, Chiang Mai; PCD = Pollution Control Department, Bangkok; MDE = Maryland Department of Environment, USA.

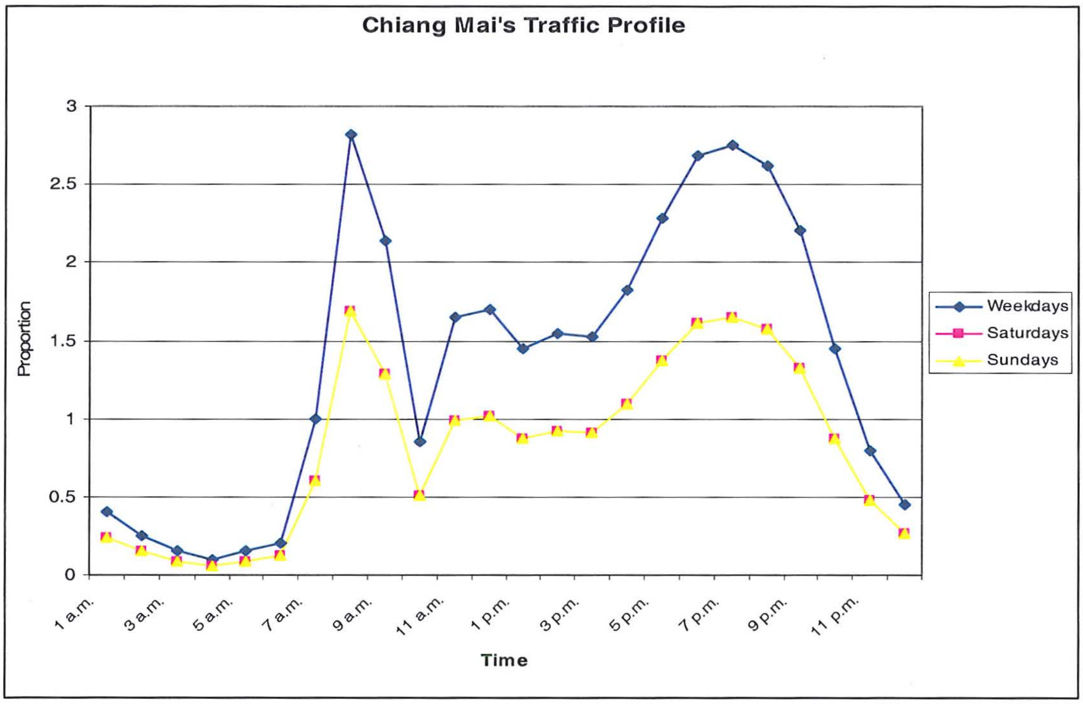


Figure 2.5 Traffic profile chart used to determine temporal changes in traffic flow for input into ADMS-Urban

(iv) As part of model validation, the numerical outputs from different model runs were compared with average monitored pollutant concentrations in order to examine the predictive capability of the model with different model options selected (e.g. different chemistry modules). In general, model validation involves comparison of model inputs with a dataset of monitored pollutant concentrations. For all three phases, monitored monthly averages, from PCD's monitoring stations for February (a dry season month) and August 2001 (a wet season month) were chosen in order to make a comparison over the annual range of conditions.

(v) The scenario that gave numerical outputs that were closest to the measured concentrations of air pollutants was chosen to run the model for a 24-hr simulation with meteorological data, in order to identify the school 'hot-spots' for use by the study of prevalence of asthma and allergies in school children. In Phase II, 24-hr PM_{10} concentrations were monitored by a MiniVol sampler at 6 school locations (where the study of the prevalence of asthma and allergies were conducted) during an air pollution episode in Chiang Mai (24 February to 4 March 2004) to investigate whether ADMS-Urban was able to predict PM_{10} concentrations in a short-term episodic period. In this phase, the Derwent-Middleton correlation scenario, with diurnal traffic data included, provided the closest fit to the measured data and was selected for the identification of pollution 'hot-spots'.

(vi) Contour plots were produced for different air pollutants, using a Chiang Mai base map. The option of Intelligent Grid Output was chosen for mapping. CERC (2003a) recommended to select this option (instead of the Regular Grid) because by using it, ADMS-Urban will create 15,000 additional receptor points in and around roads in order to improve the accuracy of plotted concentrations (contour plots) on the pictorial outputs (pollution maps).

(vii) For Phase III (February 2005 – April 2005) of the air modelling exercise, the Atmospheric Emissions Inventory Toolkit (EMIT) *version 2.1* was employed. This is a software tool to store, manipulate, and assess emission data from a variety of sources. EMIT stores emission data that are directly input, but can also calculate emissions from source activity data (e.g. traffic flow, speed and road length) using up-to-date emission factors (e.g. Euro motor vehicle exhaust emissions) (CERC, 2003b). In this study, EMIT was used to calculate emissions from all sources for a 1km x 1km grid, before exporting data to ADMS-Urban. The sources included in the model runs for Phase III, were road traffic, point, area, and grid sources. The road and point sources were the same as those employed for Phase I and II, but the area and grid sources were novel (see Figures 2.6 – 2.13).

In order to improve the quality of background emissions data inputs in Phase III, EMIT was applied including emissions from all sources in each grid cell as well as modelling existing point, area and road sources. This was recommended by CERC in order to improve the model predictions (pers. comm., Dr. Patricia Gilmour). The large modelling area of Chiang Mai was divided into over 500 (1km x 1km) grid squares. The Chemical Reaction Scheme with Trajectory Model option was also recommended by CERC to use when modelling a large area divided into hundreds of grid squares (pers. comm., Dr. Xiangyu Sheng). ADMS-Urban uses a simple Lagrangian Trajectory model to calculate background pollutant concentrations for the air along trajectories approaching the main model domain, containing all individually defined sources, receptor points and output grids. The Trajectory Model allows the main model domain to be nested within a larger domain, such as a large urban conurbation where the effects of emissions over the whole area need to be considered (as in the Chiang Mai case) (CERC, 2003a). When this option is selected, the model assumes that meteorological parameters and emissions are constant over each grid square within the Trajectory Model, and pollutants are removed from the atmosphere by dry deposition at the surface. The model initializes its calculations using background concentrations specified by the user. Concentrations are then calculated along the trajectory (path) from the edge of the domain to the receptor point, grid square by grid square (CERC, 2003a).

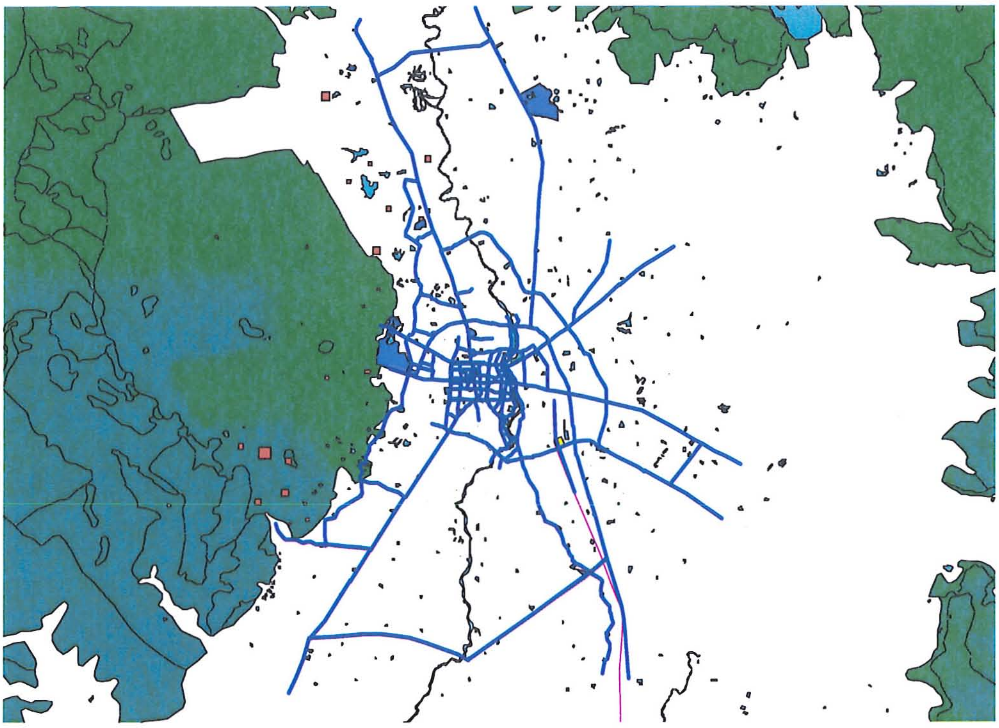


Figure 2.6 Road sources (blue lines) for ADMS-Urban modelling in Chiang Mai. The green areas represent mountains and forests.

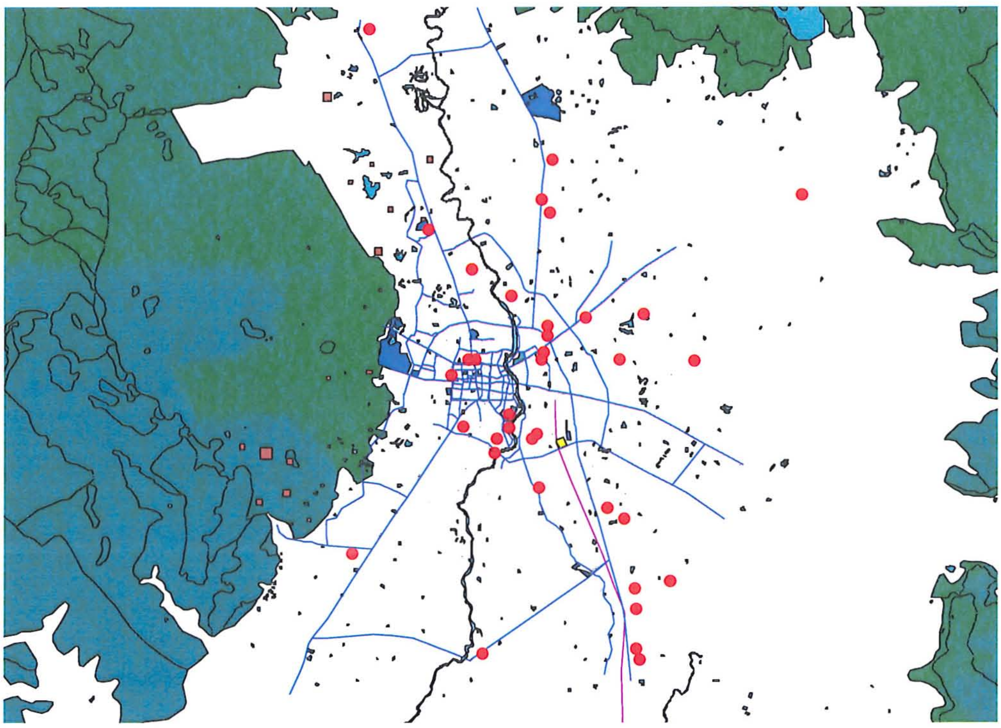


Figure 2.7 Point sources (red dots) for ADMS-Urban modelling in Chiang Mai

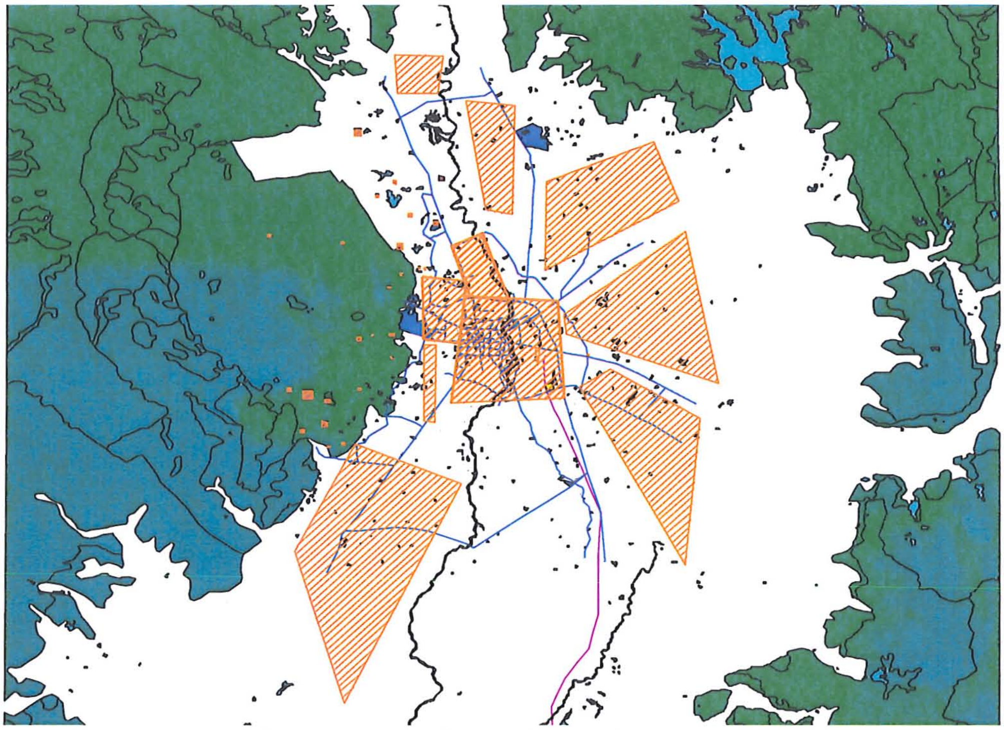


Figure 2.8 Area sources (cross hatched areas) for ADMS-Urban modelling (February), Phases I and II

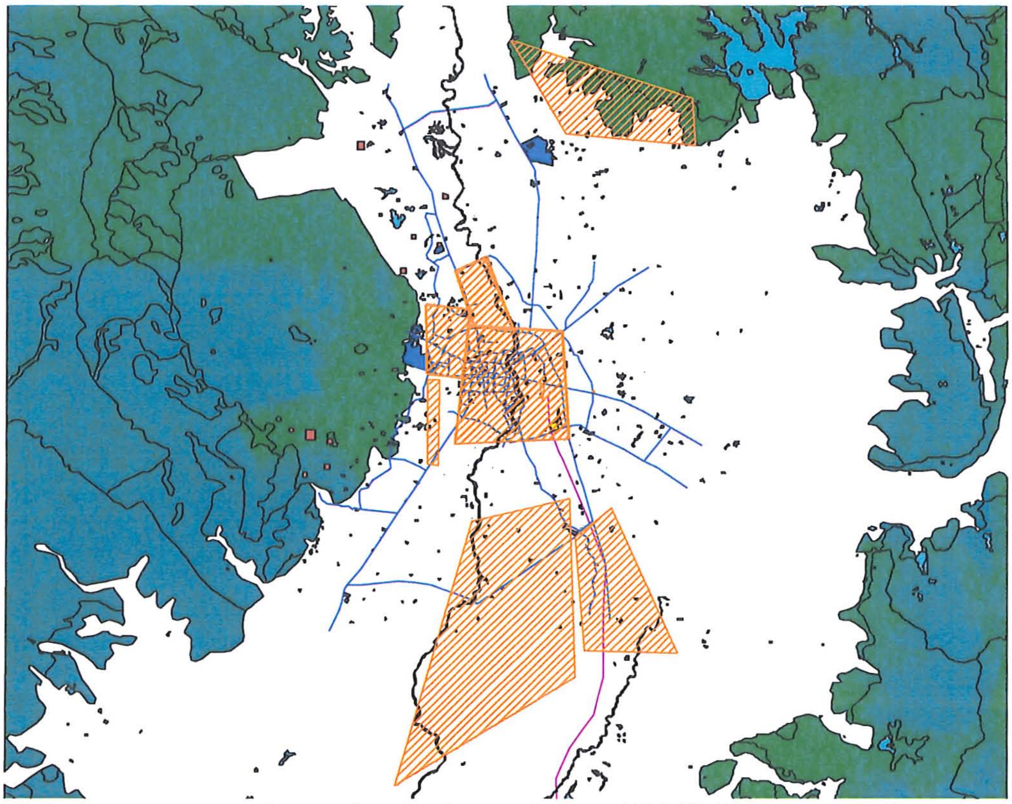


Figure 2.9 Area sources (cross hatched areas) for ADMS-Urban modelling (August), Phases I and II

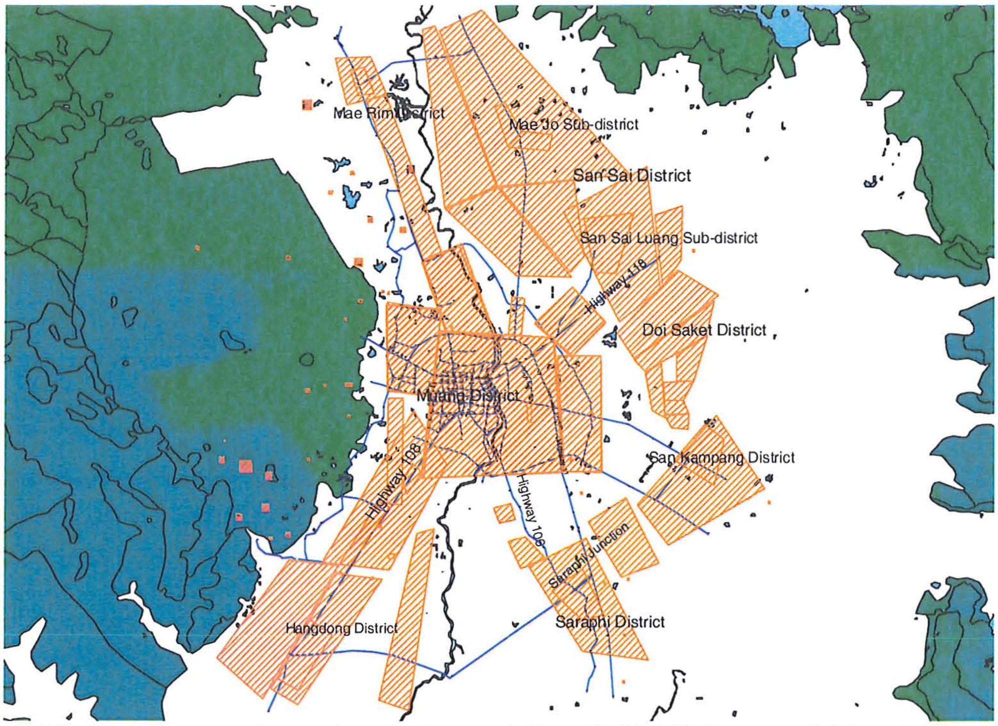


Figure 2.10 Area sources (cross hatched areas) for ADMS-Urban modelling (February), Phase III

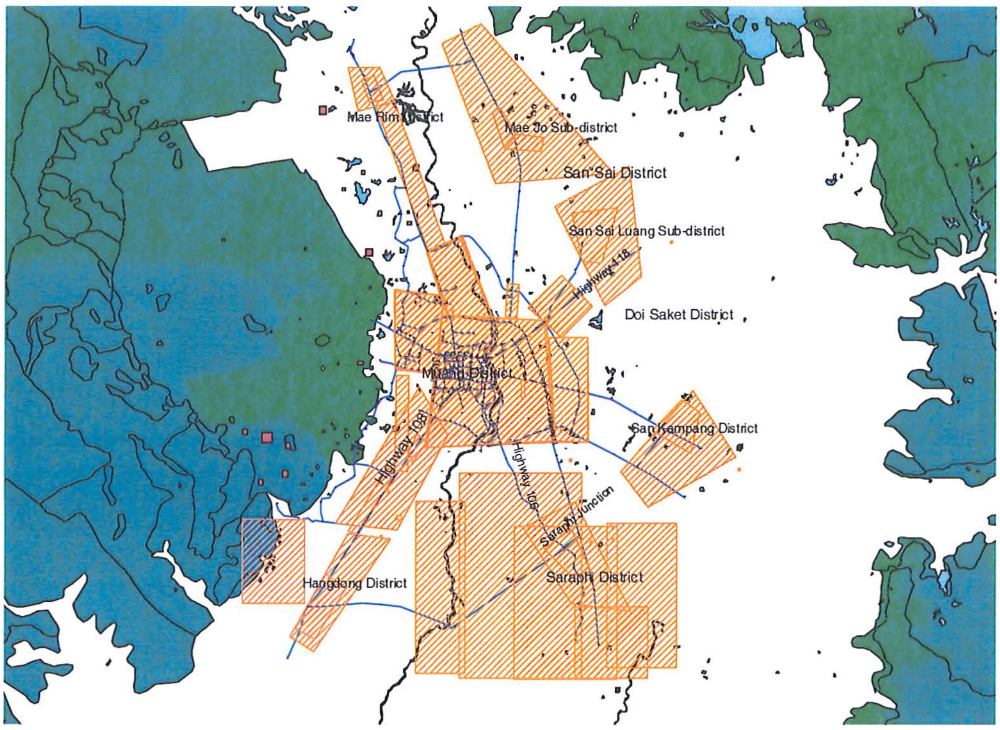


Figure 2.11 Area sources (cross hatched areas) for ADMS-Urban modelling (August), Phase III

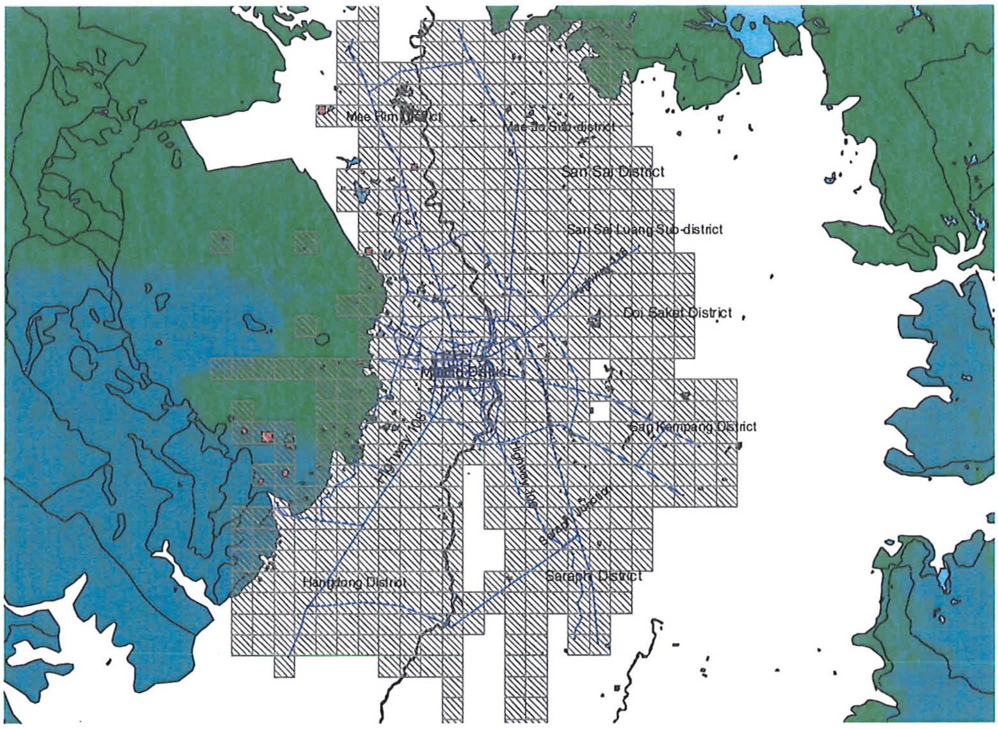


Figure 2.12 Location of grid sources for ADMS-Urban modelling (February), Phase III

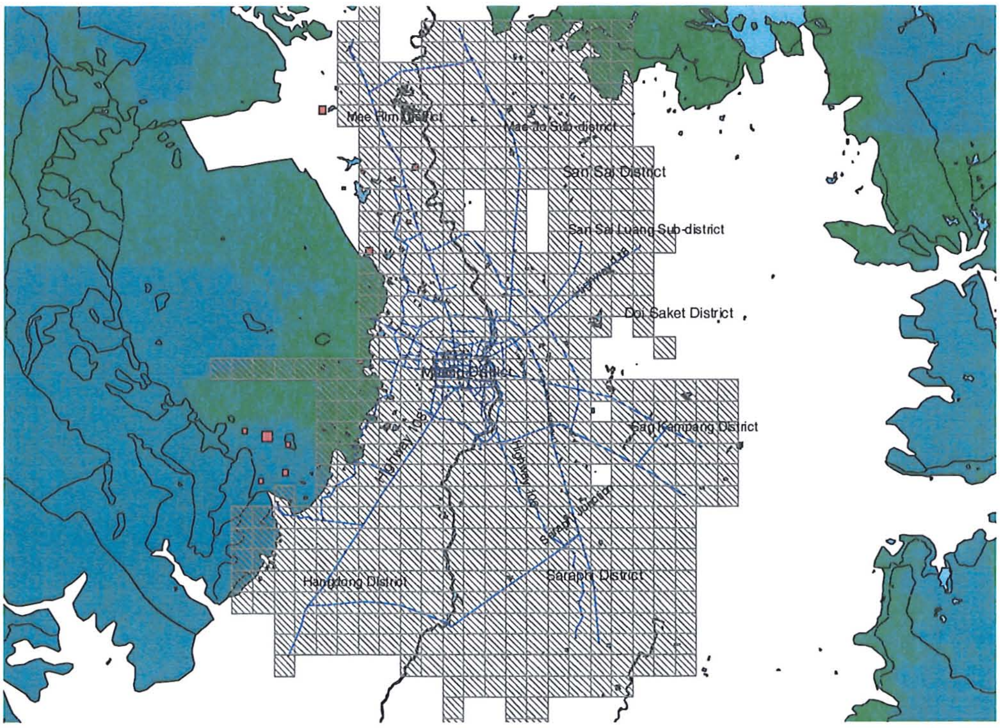


Figure 2.13 Location of grid sources for ADMS-Urban modelling (August), Phase III

2.4 ADMS-Urban Input Data

As mentioned in Section 2.2.1, the source data input into ADMS-Urban are based on the emissions inventory developed by the MDE project, except road sources which were based on the 2002 OCMRT project data. The input data for ADMS-Urban are summarised as follows:

2.4.1 Source data

i) Roads – the data entered for each road were:

- Elevation of road;
- Road width (building edge to building edge);
- Canyon height;
- Road geometry (GPS coordinates);
- Emissions calculated within ADMS-Urban when the following data were input into the model;
  - Vehicle count per hour (light and heavy duty vehicles)
  - Average speed (km/hr)
  - Vehicle emission rates (g/km/s).

For the OCMRT study, roads were divided into 5 - 15 nodes depending on their length. For each node, data were complied as follows: road elevation and width, building height along the road, traffic volume and speed of each hour from 0600-1800 hrs. Traffic information was available for 430 road sources and these were entered into the road source option of the model (Figure 2.6). For the first 1-month ADMS-Urban run, an average traffic speed and accumulated traffic volume was selected for the period 0600-0700 hrs (not a rush hour) to represent Chiang Mai road characteristics. This was because, normally required by ADMS-Urban, there was no available data on annual average hourly traffic flow for each road. The traffic profile (as a function of time) used in the model (Figure 2.5) was derived from the available 12-hr traffic data [6 a.m. to 6 p.m. (OCMRT, 2002)]. It was assumed that the night-time traffic profile was similar to that measured in 1993 in which the traffic volume recorded at 6 p.m. gradually fell to almost zero at 4.30 a.m. (Figure 2.5). The traffic volume during Saturdays and Sundays was about 60% of that for weekday traffic and was assumed to follow a similar pattern.

ii) Point and area sources – the data entered for each source were:

- Source type (point or area);
- Source height;
- Source diameter;
- Location (UTM coordinates);
- Exit velocity/flow rate of release;
- Exit temperature of release;
- Source location;
- Emission rates for each pollutant (g/s or $g/m^2/s$).

Figure 2.7 illustrates the location of point sources for this modelling exercise. Although there are over 2,000 factories in Chiang Mai, due to the unavailability of data, emissions from these sources were not used as inputs. Furthermore, there were data for only 30 industrial sources available, and at this stage, modelling concentrated on emissions from these. The industrial data for these 30 sources are reproduced in Appendix 4. Overall, point sources for ADMS-Urban input included 15 crematoria, 5 hospital incinerators and 30 industrial sources. For area sources, the differences between February and August are that the sources outside the city centre are mainly rice fields (rice stalk burning) in February (Figure 2.8), whereas, in August sources are dominated by burning in longan orchards (Figure 2.9). Grid sources were later included in Phase III for both months by application of EMIT software (Figures 2.12-2.13).

2.4.2 Meteorological data

Hourly meteorological data comprising near surface temperature (°C), wind speed (m/s), wind direction (degrees deviation from north), precipitation rate (mm/hr) and cloud cover (oktas) were collected for Chiang Mai. Sources of hourly meteorological data were the PCD monitoring station at Provincial Hall (temperature, wind speed, wind direction and precipitation rate) and the Northern Meteorological Centre (NMC) (cloud cover). The raw data were provided in Excel format and later were manipulated into text files (.txt) as required for ADMS-Urban (see Appendix 4). One meteorological file contains 9 columns of station code, year (YEAR), Julian day number (e.g. January 1st = 1, December 31st = 365 or 366; TDAY), local time (THOUR; 0 to 23), surface temperature (TEMP), wind speed (U), wind angel (PHI), precipitation rate (P), and cloud cover (CL), respectively. The data showed that low wind speeds are most common (see Figures 2.3 and 2.4); consequently, the ADMS model was run assuming calm conditions.

In Chiang Mai, prevailing winds are influenced mainly by the Southwesterly (mid-May to October, wet season), Northeasterly (November to March, winter), and Southeasterly (March to mid-May, summer) monsoons (Sangchan, 2005). Figures 2.3 and 2.4 illustrate wind roses for February and August 2001.

2.4.3 Air quality monitored data

Monitored data were collected from 2 air quality monitoring stations in Chiang Mai for the year 2001. The monitored data from the stations located at the Provincial Hall and Yuparaj School are considered representative of general ambient and roadside air quality by PCD (Section 1.5.2.2), respectively, and were compared with the numerical modelled results. The options selected in the ADMS-Urban programme are listed in Table 2.3. During the air pollution episode in winter 2004, an Airmetrics MiniVol™ portable sampler was used to monitor PM_{10} concentrations at 6 school locations in Chiang Mai (see Figure 4.2), which also were the locations for the study of the prevalence of respiratory diseases and allergies among school children (Chapter 4). With assistance from the Department of Chemistry, Chiang Mai University, Miss Walaya Sangchan, an MSc student at that time, conducted the PM_{10} sampling for the author while Middlesex University provided Whatmans quartz filters. The methodology of sample collection using MiniVol is summarised in Appendix 5. An Airmetrics MiniVol™ portable sampler utilised an impaction pre-separator to achieve a 10 μm aerodynamic diameter (AD) cut-off point. It operated at a flow rate of 5 l/min which was guaranteed by an internal flow meter and an integral flow control circuit. Low flow rates result in shut down of the sampler. The sampler was battery-powered using large purpose-built, rechargeable battery packs, allowing for sample runs of up to 24 hours (battery packs were recharged in the laboratory at the Department of Chemistry before each sampling). Internal circuits shut down the sampler if the battery was at low power to safeguard the life of the battery. Internal timers allowed for a range of sample periods to be pre-programmed (Moore, 2005). For this study, samples were collected over a 24 hour period. Sample times, battery numbers, filter numbers and flow rates were recorded before and after each sample run.

Table 2.3 The options selected in the ADMS-Urban programme for Chiang Mai, Thailand, 2001

ADMS Screen	Option	Option selected
1. Set up	- Name of site - Model options - Surface roughness (m) - Latitude (°) - Monin – Obukhov length (m)	Chiang Mai, Thailand Chemical reactions 1 19 30
2. Source Road source	- Automatic calculation of road traffic emissions were carried out.	Current dataset of emission factors is DMRB 1999
3. Meteorology	- Meteorology - Height of recorded wind (m) - Wind sector size (°) - Is the meteorological data site representative of the source site?	Enter from file Meteorological data are hourly sequential 10 10 Representative
4. Chemistry	- Chemistry scheme - Background concentration	Derwent/Middleton correlation (for Phases I and II); Chemical Reaction Scheme with Trajectory Model (for large and complex urban areas) - CO 110 ppb and O_3 0.3 ppb[†] (Phase I) - CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 2.2 ppb[‡] (Phases II & III) - SO_2 0 ppb[‡‡] (Phase III, February)
5. Grids	- Select output - Spacing - Specified points	Gridded & Specified points Intelligent Ambient monitoring station (x_1, y_1) Roadside monitoring station (x_2, y_2)
6. Output	- Pollutant output 1. PM_{10} 2. SO_2 3. NO_2 4. NO_x 5. CO 6. VOC	 LT 24 hrs LT 1 hr LT 1 hr LT 1 hr LT 1 hr LT 1 hr

Note: † From annual minimum ambient concentrations (2001), ‡ From annual average ambient concentrations (2001), ‡‡ advised by PCD.

Accuracy of the MiniVol samplers depends largely upon sampler flow rate calibration. The calibration for each sampling was conducted in accordance with the operation manual of MiniVol portable air sampler (Airmetrics, 2001). The detailed calibration methodology is summarized in Appendix 5. In order to avoid errors, filters were handled (e.g. weighing and storing) with extreme care. Before use, the Whatmans quartz filters were placed in labelled, clean, single vent, plastic Petri dishes and conditioned for 24 hours in a desiccator under dust-and-humidity controlled conditions. The filters were weighed under these conditions on a micro-balance scale and humidity, temperature, filter ID's and weights were recorded. The scale was calibrated before and after each weighing. Filter tongs were used to handle and manipulate filters. All filters were placed into their labelled Petri dish and into re-sealable plastic bags for transportation and only removed to be used for sampling. Used filters were again conditioned in their Petri dishes in the desiccator for a minimum of 24 hours before weighing as above on the same micro-balance scale. The MiniVol sampler is lightweight and portable and can be deployed in remote areas or at locations where no permanent air monitoring site has been established. However, the accuracy and precision of the sampler used in this study were unknown since the evaluation of these performance parameters requires collocation with another reference sampler (Hill *et al.*, 1999).

2.5 Validation

Since there were only two permanent air quality monitoring stations in Chiang Mai, these sites were selected for ADMS-Urban modelling as receptors for model validation. The programme was used to predict air pollutant concentrations at these sites (ambient site at Provincial Hall and roadside site at Yuparaj School). For validation/comparison purposes, the ambient results were taken to represent general urban background concentrations and the roadside results were taken to be equivalent to city centre concentrations.

Due to agricultural burning activities at the end of rice harvesting season in February (e.g. rice stalk burning), forest burning in February (a dry season month) and burning of longan branches and leaves in August (a wet season month), these open burning sources were included into the model as area sources in order to predict the worst-case scenario for Chiang Mai. The months February 2001 and August 2001 were therefore selected as being representative months for the dry and wet seasons, respectively. Average data (from hourly meteorological data) for February and August were used to run the model to predict air quality during these months. The results from ADMS-Urban were compared with both the measured parameters and to Thai Air Quality Standards.

Table 2.4 shows ADMS-Urban numerical outputs compared with data from the two Chiang Mai monitoring stations for the parameters PM_{10}, NO_2, SO_2 and CO. Phase II or III modelling generally gave the most satisfactory results when compared with the monitored data. This was especially true for ambient NO_2 concentrations during February 2001. For CO and PM_{10} in the same month, the ADMS-Urban outputs differed from the monitored data by less than 30%, which is considered acceptable. In contrast, the SO_2 results for February and August in Phase III did not provide a good match to the monitored data, with ADMS-Urban under-predicting SO_2 concentrations by 92-97% in February and 36-40% in

August. DMRB emission factors for motor vehicle emissions used may be too low to be applicable to the Chiang Mai situation for this modelling exercise. The MDE study reported that, in Chiang Mai municipal area, mobile sources produced the highest proportion of SO_2 emissions (approximately 96%) in comparison to point and area sources (CMM, 2002b).

The comparison of ADMS-Urban numerical outputs resulting from Phases I to III of the modelling work to measured monthly average concentrations are shown in Tables 2.4-2.7. In Phase III, validation for daily pollutant concentrations was also conducted. Measured average concentrations of PM_{10}, NO_2, SO_2, CO and O_3, for both ambient and roadside, were compared with the calculated ADMS-Urban numerical outputs. Hourly meteorological data for 24 hrs (dated 1 February 2001) were input into the model. The comparison is summarised in Table 2.8.

Table 2.4 Comparison of ADMS-Urban numerical outputs to monitored concentrations of PM_{10}, NO_2, SO_2, CO and O_3 for both ambient and roadside concentrations

Ambient February 2001	**ADMS-Urban numerical output**			**Monitored Monthly average**
	Phase I	***Phase II***	***Phase III***	
PM_{10} ($\mu g/m^3$)	1.99	46.73	47.46	34.13
NO_2 (ppb)	12.03	12.95	13.57	12.68
SO_2 (ppb)	0.02	2.21	0.08	0.88
CO (ppm)	0.20	0.95	0.94	1.01
O_3 (ppb)	-	-	12.93	34.4

Roadside February 2001	**ADMS-Urban numerical output**			**Monitored Monthly average**
	Phase I	***Phase II***	***Phase III***	
PM_{10} ($\mu g/m^3$)	4.25	47.86	48.37	109.74
NO_2 (ppb)	18.61	16.36	15.97	7.44
SO_2 (ppb)	0.09	2.25	0.10	11.54
CO (ppm)	0.35	1.03	1.01	1.89
O_3 (ppb)	-	-	11.06	19.54

Ambient August 2001	**ADMS-Urban numerical output**			**Monitored Monthly average**
	Phase I	***Phase II***	***Phase III***	
PM_{10} ($\mu g/m^3$)	1.74	46.58	47.28	68.50
NO_2 (ppb)	12.25	12.83	13.43	1.42
SO_2 (ppb)	0.02	2.21	1.35	2.79
CO (ppm)	0.47	0.94	0.94	0.88
O_3 (ppb)	-	-	13.14	15.00

Roadside August 2001	**ADMS-Urban numerical output**			**Monitored Monthly average**
	Phase I	***Phase II***	***Phase III***	
PM_{10} ($\mu g/m^3$)	4.39	48.42	48.11	27.97
NO_2 (ppb)	19.69	18.51	15.45	5.24
SO_2 (ppb)	0.09	2.25	1.36	3.62
CO (ppm)	0.37	1.06	1.00	0.70
O_3 (ppb)	-	-	11.52	7.9

Note:

Phase I **–** Only background concentrations of CO (110 ppb) and O_3 (0.3 ppb) were included in the model. These concentrations were derived from average minimum ambient concentrations (2001). No diurnal traffic flow data. The chemistry scheme selected was NOx-NO_2 correlation (the Derwent – Middleton correlation).

Phase II - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 2.2 ppb. The chemistry scheme selected was NO_x-NO_2 correlation. The 24-hr traffic flow data was included.

Phase III - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 0 ppb. The chemistry scheme selected was Chemical Reaction Scheme with Trajectory Model. The 24-hr traffic flow data was included. Grid sources were included.

Table 2.5 Comparison of ADMS-Urban numerical outputs to monthly average concentrations (results from Phase I modelling).

Ambient February 2001	ADMS-Urban numerical output *Phase I*	Monitored monthly average concentration	% Difference
PM_{10} ($\mu g/m^3$)	1.99	34.13	-94
NO_2 (ppb)	12.03	12.68	-5
SO_2 (ppb)	0.02	0.88	-98
CO (ppm)	0.20	1.01	-80

Roadside February 2001	ADMS-Urban numerical output *Phase I*	Monitored monthly average concentration	% Difference
PM_{10} ($\mu g/m^3$)	4.25	109.74	-96
NO_2 (ppb)	18.61	7.44	+60
SO_2 (ppb)	0.09	11.54	-99
CO (ppm)	0.35	1.89	-81

Ambient August 2001	ADMS-Urban numerical output *Phase I*	Monitored monthly average concentration	% Difference
PM_{10} ($\mu g/m^3$)	1.74	68.50	-97
NO_2 (ppb)	12.25	1.42	+88
SO_2 (ppb)	0.02	2.79	-99
CO (ppm)	0.47	0.88	-47

Roadside August 2001	ADMS-Urban numerical output *Phase I*	Monitored monthly average concentration	% Difference
PM_{10} ($\mu g/m^3$)	4.39	27.97	-84
NO_2 (ppb)	19.69	5.24	+73
SO_2 (ppb)	0.09	3.62	-98
CO (ppm)	0.37	0.70	-47

Note: % difference for each parameter = [(Numerical output – Monitored concentration)/higher conc.] x 100.

Phase I – Only background concentrations of CO (110 ppb) and O_3 (0.3 ppb) were included in the model. These concentrations were derived from average minimum ambient concentrations (2001). No diurnal traffic flow data. The chemistry scheme selected was NOx-NO_2 correlation (the Derwent – Middleton correlation).

Phase II - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 2.2 ppb. The chemistry scheme selected was NO_x-NO_2 correlation. The 24-hr traffic flow data was included.

Phase III - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 0 ppb. The chemistry scheme selected was Chemical Reaction Scheme with Trajectory Model. The 24-hr traffic flow data was included. Grid sources were included.

Table 2.6 Comparison of ADMS-Urban numerical outputs to monthly average concentrations (results from Phase II modelling).

Ambient February 2001	**ADMS-Urban numerical output *Phase II***	**Monitored monthly average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	46.73	34.13	+27
NO_2 (ppb)	12.95	12.68	+2
SO_2 (ppb)	2.21	0.88	+60
CO (ppm)	0.95	1.01	-6

Roadside February 2001	**ADMS-Urban numerical output *Phase II***	**Monitored monthly average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	47.86	109.74	-56
NO_2 (ppb)	16.36	7.44	+55
SO_2 (ppb)	2.25	11.54	-81
CO (ppm)	1.03	1.89	-46

Ambient August 2001	**ADMS-Urban numerical output *Phase II***	**Monitored monthly average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	46.58	68.50	-32
NO_2 (ppb)	12.83	1.42	+89
SO_2 (ppb)	2.21	2.79	-21
CO (ppm)	0.94	0.88	+6

Roadside August 2001	**ADMS-Urban numerical output *Phase II***	**Monitored monthly average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	48.42	27.97	+42
NO_2 (ppb)	18.51	5.24	+72
SO_2 (ppb)	2.25	3.62	-38
CO (ppm)	1.06	0.70	+34

Note: % difference for each parameter = [(Numerical output – Monitored concentration)/higher conc.] x 100.

Phase I – Only background concentrations of CO (110 ppb) and O_3 (0.3 ppb) were included in the model. These concentrations were derived from average minimum ambient concentrations (2001). No diurnal traffic flow data. The chemistry scheme selected was NOx-NO_2 correlation (the Derwent – Middleton correlation).

Phase II - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 2.2 ppb. The chemistry scheme selected was NO_x-NO_2 correlation. The 24-hr traffic flow data was included.

Phase III - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 0 ppb. The chemistry scheme selected was Chemical Reaction Scheme with Trajectory Model. The 24-hr traffic flow data was included. Grid sources were included.

Table 2.7 Comparison of ADMS-Urban numerical outputs to monthly average concentrations (results from Phase III modeling).

Ambient February 2001	ADMS-Urban numerical output *Phase III*	Monitored monthly average concentration	% Difference
PM_{10} (μg/m^3)	47.46	34.13	+28
NO_2 (ppb)	13.57	12.68	+7
SO_2 (ppb)	0.08	0.88	-91
CO (ppm)	0.94	1.01	-7
O_3 (ppb)	12.93	34.4	-62

Roadside February 2001	ADMS-Urban numerical output *Phase III*	Monitored monthly average concentration	% Difference
PM_{10} (μg/m^3)	48.37	109.74	-56
NO_2 (ppb)	15.97	7.44	+53
SO_2 (ppb)	0.10	11.54	-99
CO (ppm)	1.01	1.89	-47
O_3 (ppb)	11.06	19.54	-43

Ambient August 2001	ADMS-Urban numerical output *Phase III*	Monitored monthly average concentration	% Difference
PM_{10} (μg/m^3)	47.28	68.50	-30
NO_2 (ppb)	13.43	1.42	+89
SO_2 (ppb)	1.35	2.79	-52
CO (ppm)	0.94	0.88	+6
O_3 (ppb)	13.14	15.00	-12

Roadside August 2001	ADMS-Urban numerical output *Phase III*	Monitored monthly average concentration	% Difference
PM_{10} (μg/m^3)	48.11	27.97	+56
NO_2 (ppb)	15.45	5.24	+66
SO_2 (ppb)	1.36	3.62	-62
CO (ppm)	1.00	0.70	+30
O_3 (ppb)	11.52	7.9	+31

Note: % difference for each parameter = [(Numerical output – Monitored concentration)/higher conc.] x 100.

Phase I – Only background concentrations of CO (110 ppb) and O_3 (0.3 ppb) were included in the model. These concentrations were derived from average minimum ambient concentrations (2001). No diurnal traffic flow data. The chemistry scheme selected was NOx-NO_2 correlation (the Derwent – Middleton correlation).

Phase II - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 μg/m^3, and SO_2 2.2 ppb. The chemistry scheme selected was NO_x-NO_2 correlation. The 24-hr traffic flow data was included.

Phase III - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 μg/m^3, and SO_2 0 ppb. The chemistry scheme selected was Chemical Reaction Scheme with Trajectory Model. The 24-hr traffic flow data was included. Grid sources were included.

Table 2.8 Comparison of ADMS-Urban numerical outputs to daily average concentrations (results from Phase III modeling).

Ambient 1 February 2001	**ADMS-Urban numerical output *Phase III***	**Monitored daily average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	47.47	21.27	+55
NO_2 (ppb)	13.85	16.05	-14
SO_2 (ppb)	0.07	0.83	-92
CO (ppm)	0.95	0.87	-8
O_3 (ppb)	12.15	29.81	-59

Roadside 1 February 2001	**ADMS-Urban numerical output *Phase III***	**Monitored daily average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	48.01	115.21	-58
NO_2 (ppb)	16.83	12.22	+38
SO_2 (ppb)	0.08	3.05	-97
CO (ppm)	1.03	1.91	-46
O_3 (ppb)	9.50	15.17	-37

Ambient 11 August 2001	**ADMS-Urban numerical output *Phase III***	**Monitored daily average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	46.52	52.00	-11
NO_2 (ppb)	13.55	2.52	+81
SO_2 (ppb)	2.10	3.30	-36
CO (ppm)	0.94	0.87	-8
O_3 (ppb)	12.02	11.04	+8

Roadside 11 August 2001	**ADMS-Urban numerical output *Phase III***	**Monitored daily average concentration**	**% Difference**
PM_{10} ($\mu g/m^3$)	46.98	41.54	+12
NO_2 (ppb)	15.21	9.55	+37
SO_2 (ppb)	2.11	3.50	-40
CO (ppm)	0.97	1.05	-8
O_3 (ppb)	10.54	4.18	+60

Note: % difference for each parameter = [(Numerical output – Monitored concentration)/higher conc.] x 100.

Phase I – Only background concentrations of CO (110 ppb) and O_3 (0.3 ppb) were included in the model. These concentrations were derived from average minimum ambient concentrations (2001). No diurnal traffic flow data. The chemistry scheme selected was NOx-NO_2 correlation (the Derwent – Middleton correlation).

Phase II - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 2.2 ppb. The chemistry scheme selected was NO_x-NO_2 correlation. The 24-hr traffic flow data was included.

Phase III - Background concentrations were included as follows: CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 $\mu g/m^3$, and SO_2 0 ppb. The chemistry scheme selected was Chemical Reaction Scheme with Trajectory Model. The 24-hr traffic flow data was included. Grid sources were included.

2.6 Results

2.6.1 Results of Phase I Modelling

Phase I modelling using ADMS-Urban under-predicted the concentrations of PM_{10}, SO_2 and CO, but over-predicted the concentrations of NO_2. The 'hot-spots' shown in Table 2.9 were based on the pollution maps produced by the model. The main pollution 'hot-spot' areas identified by ADMS-Urban were Saraphi Junction and Highway 106 (for CO, NO_2, NO_x, PM_{10}, SO_2 and VOC), Poi Luang Junction (for VOC and NO_x), Witchayanon Road (for NO_2, NO_x, PM_{10}, and VOC), and the airports (for SO_2). The pollution 'hot-spots', with respect to each pollutant, are described in Table 2.9. The results of Phase I modelling were used to select the study areas for the questionnaire survey that was conducted in urban and sub-urban areas of Chiang Mai (Chapter 3). Although the ADMS-Urban numerical results for Phase I were not good and could not be validated by reference to measured data, the model was proven to have a predictive value in predicting relative pollution levels and hence probable highly polluted sites; particularly major junctions and roads with traffic congestion problems in Chiang Mai. Each site listed in Table 2.9 was visited to confirm if it was probably a polluted area. All of them have one feature in common; a commercial and/or residential area on a busy road. Apart from the International Airport and Airforce 41, all of the identified 'hot-spots' were located at some of the main roads in Chiang Mai urban areas and it appears that significant emission inputs are from traffic sources.

Table 2.9 Summary of pollution 'hot-spots' in Chiang Mai, including their effective area with respect to the pollutants modelled by ADMS-Urban (results from Phase I)

	Pollution 'hot-spots' [þ]			
Pollutant	**February** [†]	**Effective Area (m^2)**	**August** [‡]	**Effective Area (m^2)**
CO	Saraphi Junction and Highway 106[§]	430,866	Saraphi Junction and Highway 106[§]	418,130
NO_2	Saraphi Junction and Highway 106[§]	54,886	Saraphi Junction and Highway 106[§] Witchayanon Road	48,029 2,254
NO_x	Saraphi Junction and Highway 106[§] Poi Luang Junction	56,980 54,347	Saraphi Junction and Highway 106[§] Witchayanon Road Poi Luang Junction	332,894 53,193 18,495
PM_{10}	Saraphi Junction and Highway 106[§]	155,790	Saraphi Junction and Highway 106[§] Witchayanon Road	13,018 2,253
SO_2	International Airport & Airforce 41	1,992,282	International Airport & Airforce 41	615,956
VOC	Saraphi Junction and Highway 106[§] Boonruangrit-Maneenoparat-Huay Kaew Roads Sriphum Road (Sompetch Market) Poi Luang Junction	825,947 658,453 85,551 75,383	Saraphi Junction and Highway 106[§] Witchayanon Road Maneenoparat Road Maneenoparat-Witchayanon Junction Tunghotel-Train Station Junction Huay Kaew Road	734,892 21,623 31,439 12,872 12,631 9,275

Note: [†] Dry season month; [‡] rainy season month; [§] south of Saraphi Junction; [þ] Hot-spots were considered from the highest range of maximum concentrations – PM_{10} 50-60 µg/m^3; NO_2 90-200 ppb; NO_x 240-600 ppb; CO 2-5 ppm; SO_2 0.55-0.65 ppb; VOC 60-260 ppb.

2.6.2 Results of Phase II Modelling

Phase II of the modelling of air quality was conducted using a more specific, smaller scale (500m x 500m) grid in order to identify 'hot-spots' containing schools located close to busy roads (see Figures 2.14-2.16). These schools were then used for the survey of respiratory diseases and allergies among school children in Chiang Mai (Chapter 4). The model was run for one day in February (24 lines of meteorological data to represent one typical day in the dry season). Daily PM_{10} data between 1997-2002, from both PCD monitoring stations in Chiang Mai, showed that PM_{10} concentrations normally exceeded the Thai national standard (120$\mu g/m^3$) during February to March (middle to the end of dry season) (source: Pollution Control Department electronic data). Numerical outputs of average and maximum pollutant concentrations were derived for four identified schools: one located on Highway 106, south of Saraphi Junction (Figure 2.14); and three located on Highway 108 (Figures 2.15 and 2.16). In order to compare predicted PM_{10} concentrations with measured concentrations, roadside PM_{10} concentrations were monitored for 24 hours in front of each school. The PM_{10} concentrations measured at the four urban schools were as follows: at Wat Sripotaram School (161$\mu g/m^3$); at Tao Bunruang School (186$\mu g/m^3$); at Ban San Pasak School (241$\mu g/m^3$); and at Ban Donpin School (192$\mu g/m^3$). These levels were all substantially higher than those calculated using ADMS-Urban (Table 2.10). They were also higher than the Thai air quality standard for PM_{10} (120$\mu g/m^3$). The monitored concentrations of PM_{10} at the two suburban schools were: Ban Korn Tal School (132$\mu g/m^3$) Wat Sai Moon School (210$\mu g/m^3$). These also were much higher than the ADMS-Urban predictions and higher than the air quality standard, and similar to those measured at the urban school sites. Nevertheless, Table 2.10 shows that the air concentrations of PM_{10} monitored at the suburban 'non hot-spot' schools (S1 and S2) were at or below ambient concentrations; whereas for the four urban schools (S3 – S6) in the identified urban 'hot-spots', monitored concentrations were significantly greater than the prevailing ambient levels. This observation is consistent with the 'hot-spot'/'non hot-spot' categorization of the school sites. For all schools, however, the measured levels of PM_{10} were similar to those measured by the Chiang Mai PCD at its ambient air monitoring station and it is acknowledged that general air quality at the time of monitoring was atypical – Chiang Mai having a serious respirable dust problem during January – March 2004. The results are consistent with the suggestion that PM_{10} levels vary little over large areas of the province. They also suggest that predicted differences in air quality, with respect to PM_{10} at 'hot-spot' and 'non hot-spot' locations, are smaller than, and masked by, the day-to-day variations in levels across the whole area.

Table 2.10 Numerical outputs from the ADMS-Urban model of average PM_{10} concentrations at four schools in predicted 'hot-spot' areas and two schools in a predicted 'non hot-spot' area – compared with monitored data and ambient data collected for the same day.

School	X(m) †	Y(m) †	ADMS-Urban Average PM_{10} (24hr) ($\mu g/m^3$)	Monitored PM_{10}* ($\mu g/m^3$)	PM_{10} ambient concentration** ($\mu g/m^3$)
S1 Ban Korn Tal	496798	2090749	45.91	132	186
S2 Wat Saimoon	491458	2065803	46.42	210	204
S3 Wat Sripotaram	504268	2068229	63.16	161	112
S4 Tao Bunruang	492930	2068185	58.62	186	132
S5 Ban San Pasak	493614	2069269	51.76	241	162
S6 Ban Donpin	495271	2071787	58.25	192	90

Note: Schools S1 and S2 are located in a 'non hot-spot'; and Schools S3 –S6 in 'hot-spots'. * Monitored by MiniVol for 24 hrs during air pollution episode (24 February to 4 March 2004) in Chiang Mai. ** Monitored by an automatic ambient air monitoring station of the Pollution Control Department, comparison on the same date as MiniVol monitoring. † UTM coordinates.

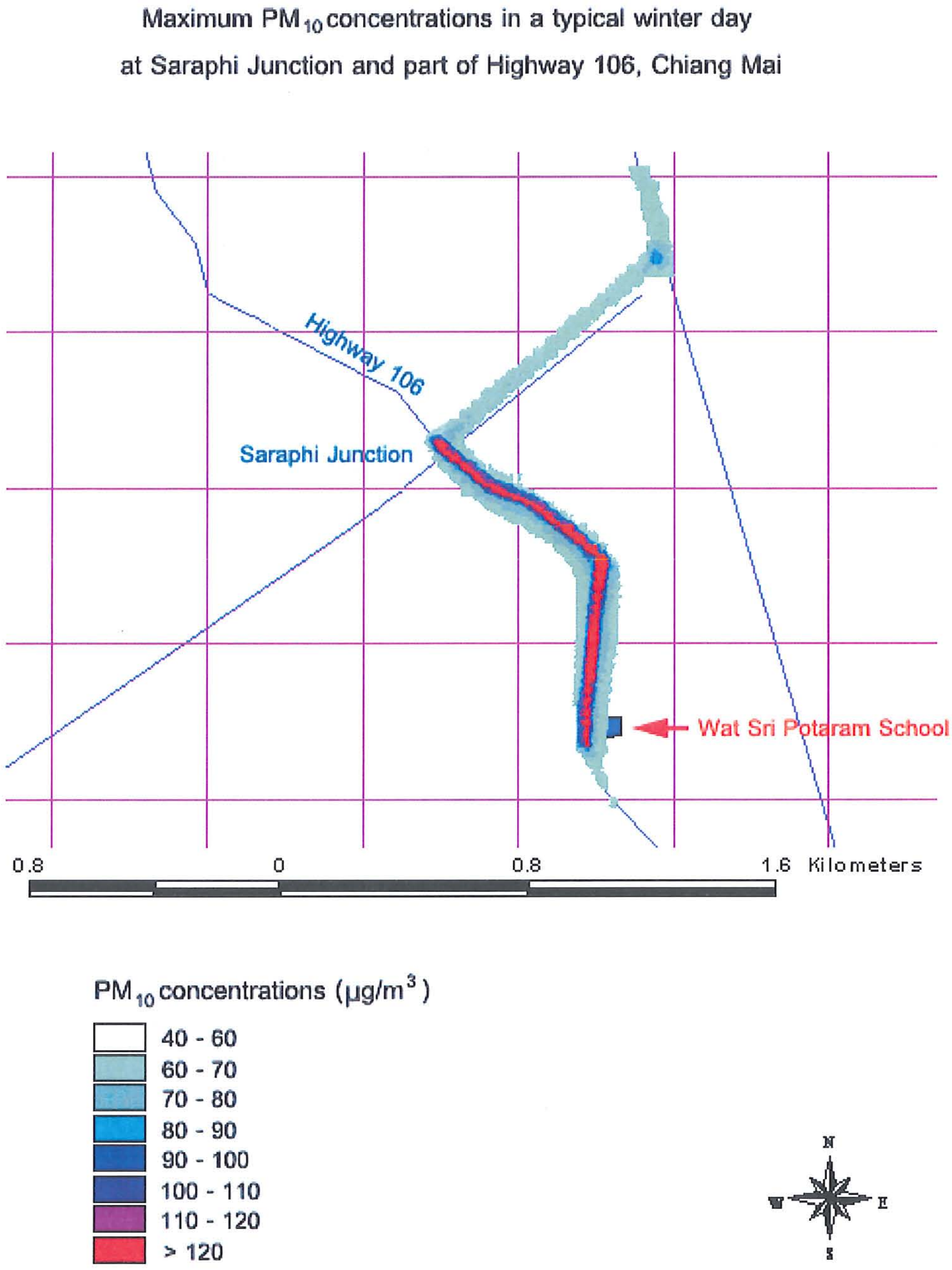


Figure 2.14 Maximum PM_{10} concentrations predicted for a typical winter day at Saraphi Junction (Phase II modelling exercise). The small blue rectangle at the southern end of the PM_{10} plume marks the location of the Wat Sri Potaram School.

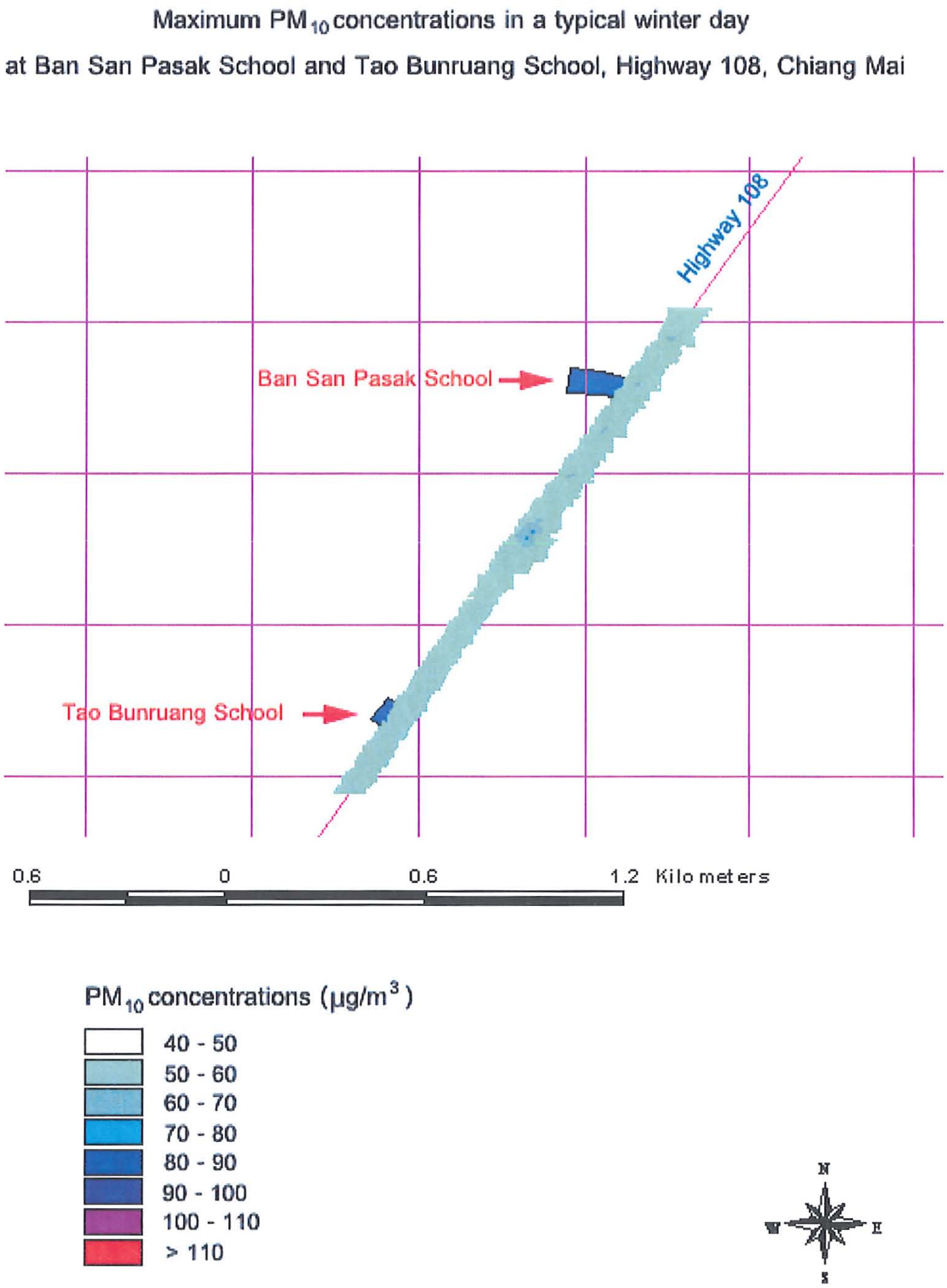


Figure 2.15 Maximum PM_{10} concentrations predicted for a typical winter day (Phase II modelling exercise) in the region close to Ban San Pasak (upper) and Tao Bunruang (lower) Schools (shown as blue rectangles adjacent to the path of the main road).

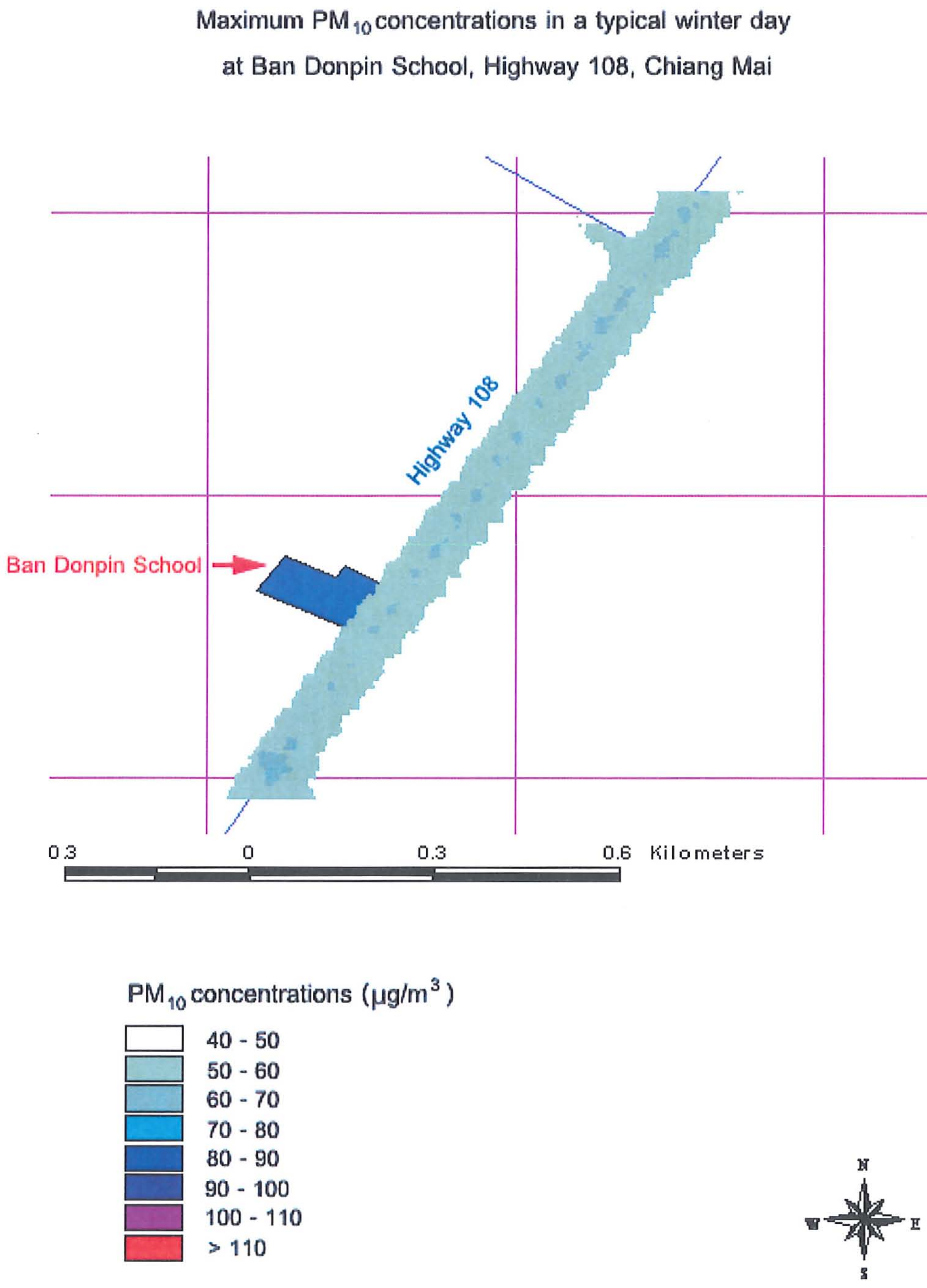


Figure 2.16 Maximum predicted PM_{10} concentrations for a typical winter day adjacent to Ban Donpin School (Phase II modelling exercise).

2.6.3 Results of Phase III Modelling

The ADMS-Urban outputs differ from the monitored concentrations by generally less than 30%, which is considered acceptable for this modeling exercise. The outputs from Phase III modelling are mostly satisfactory in terms of the numerical data and the pictorial outputs are little different to those produced by the Phase II modeling. However, one more 'hot-spot' for PM_{10} pollution was identified during Phase III, at Hangdong-Sameong Junction within the larger area of Hangdong District (Figure 2.17). In addition, a further possible area of high PM_{10} pollution on Witchayanon Road, Muang District near the city centre was identified in Figure 2.18.

In Phase III, model inputs included grid sources. These were incorporated in conjunction with the Chemical Reaction Scheme with Trajectory Model option (see 2.3.3 vii). The results gave the best fit to monthly average concentrations: ambient PM_{10} and CO in both February and August; ambient NO_2 in February; roadside CO in August; and ambient and O_3 in August (see Table 2.7). Considering the 30% acceptable difference for each pollutant, Phase III produced more accurate/better numerical outputs than the Phase II modelling (Table 2.4). A comparison of ADMS-Urban numerical outputs and monitored daily average concentrations was also made (Table 2.8). The model in Phase III produced a good fit for ambient and roadside PM_{10} and CO in August, ambient NO_2 and CO in February, and ambient O_3 in August.

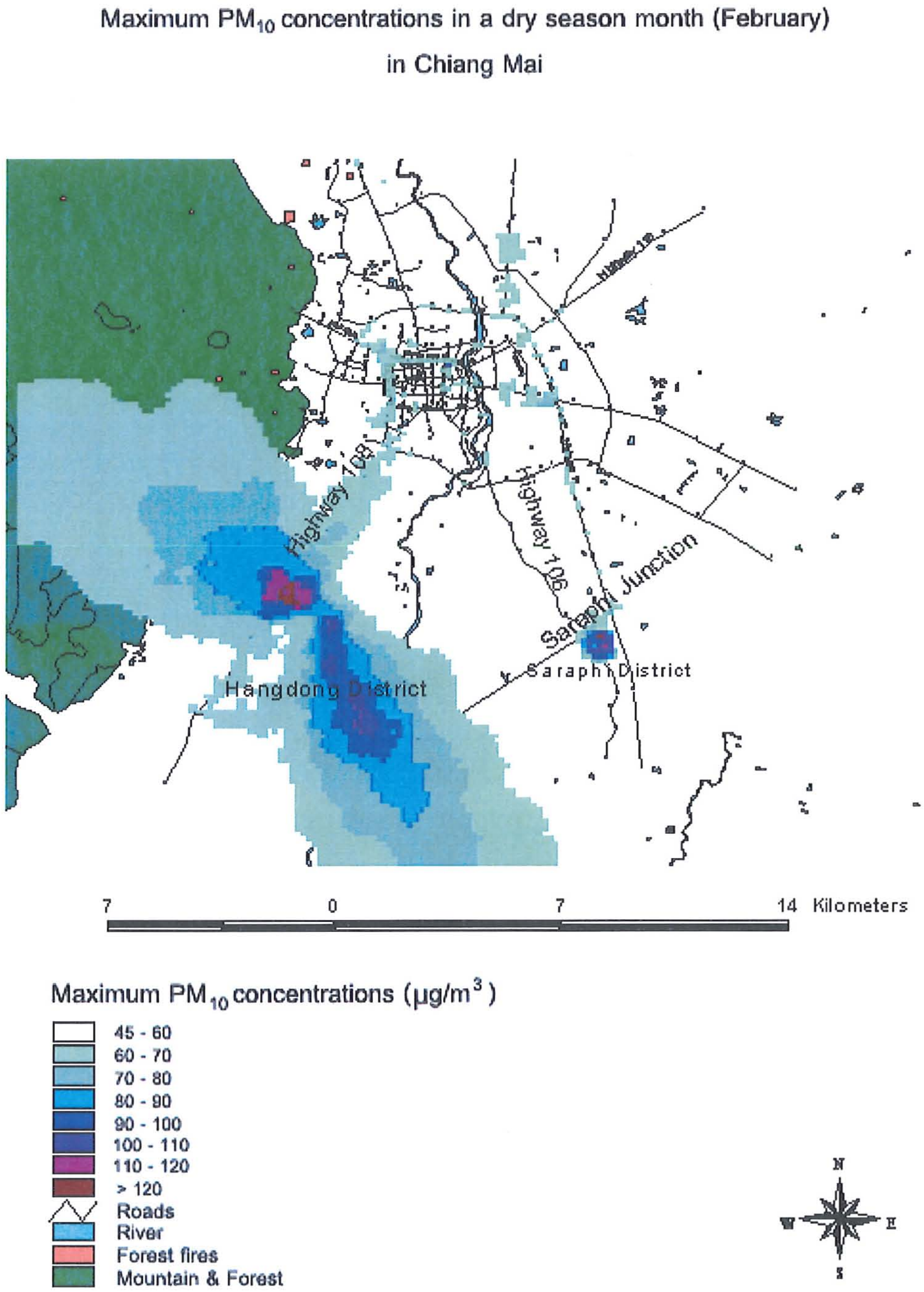


Figure 2.17 Predicted maximum PM_{10} concentrations in February 2001 in the greater Chiang Mai area. Major polluted districts are in the Hangdong and Saraphi Districts (results from Phase III modelling exercise).

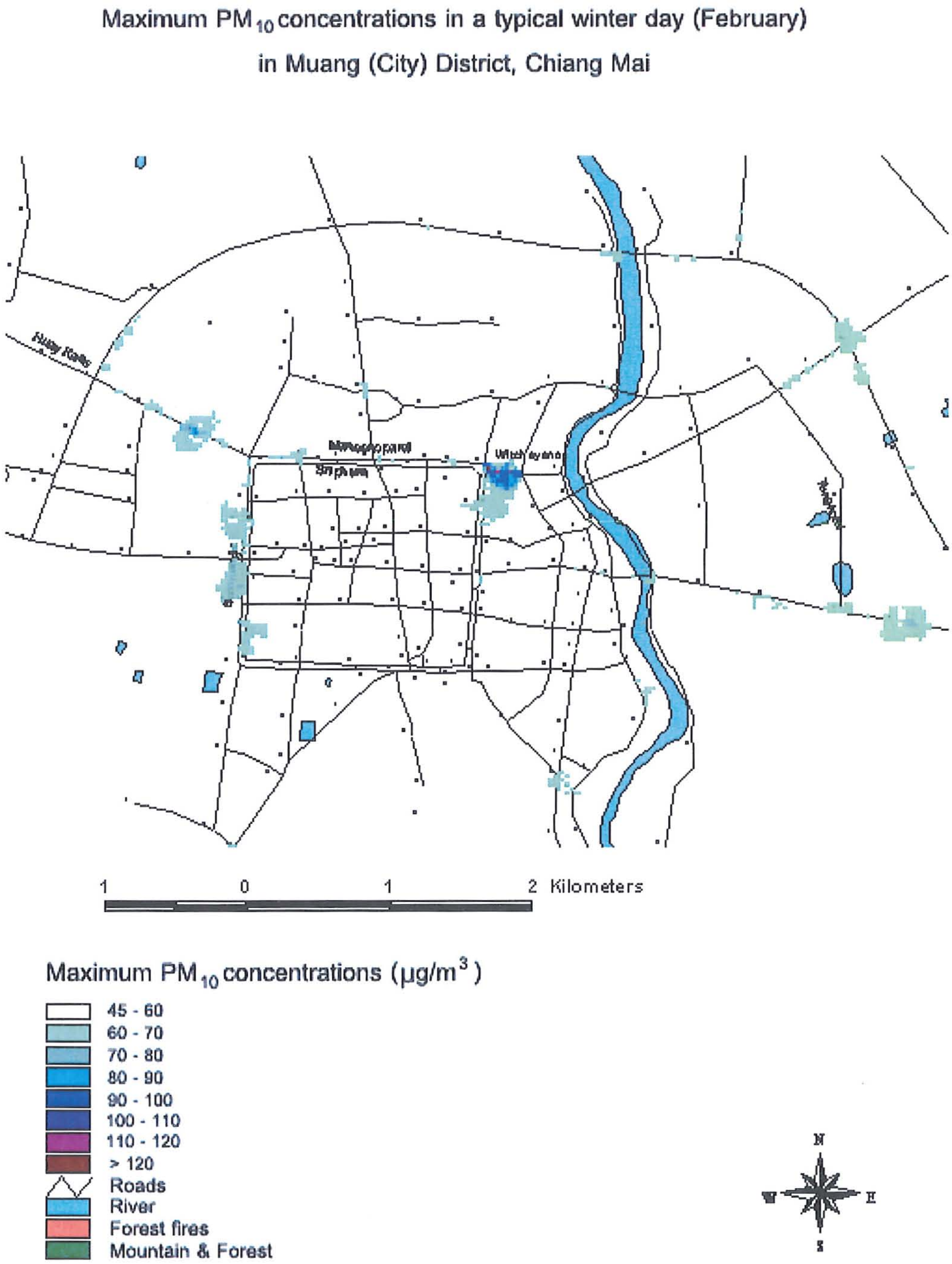


Figure 2.18 Predicted maximum PM_{10} concentrations in February 2001 on Witchayanon Road, Muang (City) District, Chiang Mai (results from Phase III modelling exercise)

2.7 Discussion

The results of ADMS-Urban modelling results are closer to monitored air quality data when the background concentration of each pollutant (as annual minimum concentration), and 24-hr traffic flow data were input into the model and the Chemical Reaction Scheme with Trajectory Model option was selected (as in Phase III). Due to the lack of air quality data for many areas of Chiang Mai, ADMS-Urban was found to be a useful tool for the identification of suitable locations for subsequent research components; specifically conducting a questionnaire survey regarding residents' attitudes towards air pollution in their home areas and their quality of life (Chapter 3), and a study of the prevalence of respiratory and allergic diseases among school children in Chiang Mai (Chapter 4). However, its usefulness as a tool to accurately predict the absolute concentrations of air pollution is limited in Chiang Mai due to the prevalence of very low wind speeds and complex topography. Even if a comprehensive set of all pollution sources with local emission rates could have been compiled and input into the model, these major limitations of ADMS-Urban would still probably restrict the accuracy of modelling results (see Section 1.5.1 i).

Tables 2.11-2.12 illustrate the extent of deviation between model-predicted and measured air pollution levels (Phase I-III predictions). Across all pollutants, Phase II inputs gave the most accurate numerical outputs with the lowest median level of inaccuracy (+4%), however the median inaccuracy in Phase II was not much different to that for Phase III (-9.5%). However, these values do not adequately reflect the general accuracy of the model runs since, for both runs, the relative accuracy is, to a large extent, achieved because both large and small positive and negative errors for individual pollutants effectively cancel each other out. Overall, for both sets of input data and for both August and February the phase II inputs produce smaller deviations for individual pollutants and can be considered most accurate. This is so even though most of the input data, in particular point and road sources, was the same for both Phase II and Phase III calculations.

Table 2.11 Summary of % difference in concentrations between ADMS-Urban numerical outputs and monitored monthly averages. The median of % difference is shown for each calculation phase.

Pollutant	Location/Month	% Difference		
		Phase I	*Phase II*	*Phase III*
PM_{10}	A/F	-94	+27	+28
	R/F	-96	-56	-56
	A/A	-97	-32	-30
	R/A	-84	+42	+56
Median		**-95**	**-2.5**	**-1**
NO_2	A/F	-5	+2	+7
	R/F	+60	+55	+53
	A/A	+88	+89	+89
	R/A	+73	+72	+66
Median		**66.5**	**63.5**	**59.5**
SO_2	A/F	-98	+60	-91
	R/F	-99	-81	-99
	A/A	-99	-21	-52
	R/A	-98	-38	-62
Median		**-98.5**	**-29.5**	**-76.5**
CO	A/F	-80	-6	-7
	R/F	-81	-46	-47
	A/A	-47	+6	+6
	R/A	-47	+34	+30
Median		**-63.5**	**0**	**-0.5**
O_3	A/F	-	-	-62
	R/F	-	-	-43
	A/A	-	-	-12
	R/A	-	-	+31
Median		**-**	**-**	**-27.5**
Median (all pollutants)		**-82.5**	**+4.0**	**-9.5**

Note: A/F = Ambient/February; R/F = Roadside/February; A/A = Ambient/August; R/A = Roadside/August

Considering each pollutant in turn, Phase III inputs have the lowest median levels of inaccuracy for PM_{10} (-1%) and NO_2 (59.5%), however, they were not much different from Phase II values (-2.5% for PM_{10} and 63.5% for NO_2). For SO_2 and CO, Phase II produced the most satisfactory results because it gave the lowest medians of inaccuracy (-29.5% for SO_2 and 0% for CO). Nevertheless, Phase III gave only a slightly greater level of inaccuracy for CO (-0.5%).

Table 2.12 The extent of deviation between model-predicted air pollution levels (Phase I – III predictions) and measured air pollutant concentrations. Key: + = within ±30% limit of acceptability, b = 31 – 50% below limit, B = >50% below limit, a = 31 – 50% above limit, A = >50% above limit.

Pollutant	Location/Month	% Difference		
		Phase I	*Phase II*	*Phase III*
PM_{10}	A/F	B	+	+
	R/F	B	B	B
	A/A	B	b	+
	R/A	B	a	A
NO_2	A/F	+	+	+
	R/F	A	A	A
	A/A	A	A	A
	R/A	A	A	A
SO_2	A/F	B	A	B
	R/F	B	B	B
	A/A	B	+	B
	R/A	B	b	B
CO	A/F	B	+	+
	R/F	B	b	b
	A/A	b	+	+
	R/A	b	a	+
O_3	A/F	-	-	B
	R/F	-	-	B
	A/A	-	-	+
	R/A	-	-	A

Note: A/F = Ambient/February; R/F = Roadside/February; A/A = Ambient/August; R/A = Roadside/August

It would seem that the inclusion of grid source inputs over a large area for Phase III did not have a significant effect on predicted pollutant concentrations. This is believed to be mostly due to the low emission velocity (0.1m/s) input into EMIT for pollutants produced by agricultural burning sources and forest fires. It is possible that these velocities were unrealistically low. However, the modelling in Phase III gave the best fit with respect to monitored data for ambient concentrations. Phase II gave the best fit for roadside concentrations in August. Phase I outputs were the least accurate. Improvement of input data (e.g. more comprehensive characterization of pollution sources, traffic variations, etc.) may improve model predictions. CO predictions were generally within ±50% of monitored values for all three modeling phases whereas ambient PM_{10} predictions were most accurately predicted by Phase III calculations. This may be due to the inclusion of grid sources including additional industrial sources, such as cement plants, in the model inputs. Nevertheless, roadside PM_{10} predictions remained relatively inaccurate for Phase III. NO_2 predictions were usually significantly higher – and never less than – the monitored levels. This is most likely because the chemical reaction scheme in the ADMS-Urban model is not applicable for the Chiang Mai atmosphere, where high solar UV radiation causes significant levels of photolysis, forming NO and O_3 faster than in the UK atmosphere. In addition, the predicted O_3 concentrations in February were lower than the monitored concentrations, which similarly may be caused by the model's chemical reaction scheme that was designed for climatic conditions prevailing in the UK.

It can be seen from the above that ADMS-Urban consistently under-predicted PM_{10} concentrations, particularly roadside concentrations. This may be because there are air pollution sources in addition to traffic on adjacent roads, which may augment PM_{10} concentrations near the roadside monitoring station in Yuparaj School. The numbers of motor vehicles (traffic data) were counted on the main roads, near the roadside monitoring station, but not the vehicles of parents and teachers that travelled in and out the school area. The over-prediction of roadside PM_{10} concentration in August (a wet season month) may be due to the assumed background concentration of 45.6$\mu g/m^3$ which, although it was the annual average for 2001, may be untypical and too high for the wet atmospheric conditions prevailing at the time of monitoring. In general, sources of PM_{10} outside the Chiang Mai Comprehensive Urban Plan, including trans-boundary PM_{10}, were not included in the model. Other sources, contributing to the PM_{10} concentrations in Chiang Mai, such as other factories, road and building construction were also not included because of a lack of data. It is clear that due to the variable atmospheric conditions and air polluting activities during different months and years, many more realistic background PM_{10} concentrations (monthly and annually) should be compiled to provide a more secure basis for modelling. Furthermore, ADMS-Urban calculated only primary PM_{10} from the sources input into the model, but secondary components are also generally present in the atmosphere, including ammonium sulphate, ammonium nitrate and resuspended particles, but these were not considered. This omission would tend to cause an underestimation of PM_{10} concentrations. Such background PM_{10} data is generally very important for a modelling study and would have been included in this study had it been available.

In Phase II, the predicted roadside concentrations of SO_2 were lower than the monitored concentrations for both February and August (Table 2.12). For NO_2, the predicted concentrations were significantly higher than the monitored levels, although the predicted concentration for the ambient station in February (12.03ppb) is slightly lower than the monitored concentration (12.68ppb). Again, this is most likely because ADMS-Urban assumes a certain chemical relationship between NO_x and NO_2 that may not be suitable for Chiang Mai conditions. The Derwent/Middleton correlation was chosen to model NO_2 concentrations for given NO_x emissions. This correlation is based upon UK monitored data under UK meteorological conditions and requires detailed input data such as background NO_x, NO_2, and O_3 concentrations. However, this is unlikely to be representative of Chiang Mai meteorological conditions as the conversion rates of NO_x to NO_2 are not likely to be consistent with a tropical climate.

In February (a dry season month), CO, SO_2 and PM_{10} concentrations calculated using the ADMS-Urban model were generally lower than monitored concentrations, which is probably due to the prevalence of forest fires and rice stalk burning at this time of the year. The emission rates ($g/m^2/s$) used in the model, derived from annual average emission rates for these sources would almost certainly be too low for a month when burning activity is at its maximum. In addition, data on SO_2 emissions from industrial combustion in many factories were not available and this also would have affected the accuracy of the model predictions.

In August, (a wet season month), pollutant concentrations are likely to be lower than in the dry season, because of higher precipitation rates that cause washout of some pollutants, especially particulates (PM_{10}). Emissions from forest fires and rice stalk burning in rice fields were taken out of the model for this month, but the agricultural burning from orchards was included. This is because 'longan' fruit farmers normally burn dry branches and leaves after harvesting, around this time of the year. Despite this, seasonal differences in predicted pollutant concentrations between dry and wet season were not apparent in this study.

The average predicted and monitored pollutant concentrations, over one month (February 2001), were compared to Thai air quality standards. The 24-hr average PM_{10} and 1 hr average SO_2, NO_2 and CO concentrations were calculated by the model using a data set containing hourly meteorological variables over the month. In comparison to the Thai standards, both modelled and monitored PM_{10}, SO_2, NO_2 and CO concentrations, recorded at both ambient and roadside sites, did not exceed the standards. In order to make recommendations for further improvement of the ADMS-Urban results for Chiang Mai, the stated limitations in the modelling input data should be addressed. Additionally, to better represent PM_{10} concentrations, further information is required on background, secondary and natural concentrations and sources of PM_{10} inside and outside the study area.

In terms of application to the Chiang Mai situation, the ADMS-Urban dispersion model was generally easy to use because it is PC-based, and its 'Windows' based user-interface was straightforward and therefore easy to learn and use. It is also readily-interfaced to Geographical Information Systems (GIS), such as ArcView. Such an interface allows the pollutant concentrations (numerical outputs) to be plotted and predicted for specific locations. In addition, the pictorial outputs such as contour plots, over-laid onto available base maps of Chiang Mai urban areas, can be used to illustrate the probable location of air-pollution 'hot-spots' for different types of pollutants. These enable researchers and people with limited technical backgrounds, to locate and better understand areas of concern with respect to air pollution. Also, this information is very helpful to decision-makers, such as government officials, who need to establish future air quality management plans for Chiang Mai. Without such models it is difficult for planners to take account of the multiple point sources of pollution in an area and of changes in the number and distribution of such sources with time. For example, while the model was able to calculate pollution distributions, taking into account many sources [1104 sources (541 grid source cells; 50 point and 92 area sources; 421 road sources) in February, and 1071 sources (545 grid source cells; 50 point and 55 area sources; 421 road sources) in August], a planner without such a model would find this impossible to achieve.

With respect to model validation the results produced by ADMS-Urban were not as good as expected. For the roadside location in August, most pollutants, particularly PM_{10}, NO_2, and O_3, were over-predicted. It would seem that the chemistry schemes (the Derwent – Middleton correlation, and the Chemical Reaction Scheme) selected for modelling may be less appropriate for August, a wet season month. It is possible that the wet deposition module could be selected to take account of the washout of both gaseous and particulate pollutants by rainfall. This may be so even though the wet deposition module is generally regarded as more appropriate for particulates (CERC, 2001). In this respect it should be noted that the option *Chemical Reaction Scheme with Trajectory Model* was used because it was recommended by CERC for use when modelling the large area of Chiang Mai, where hundreds of grid source cells were included in the model domain. This is because this chemistry option is used to represent the physical and chemical processes that can occur in the atmospheric boundary layer over very large urban areas, where the effect of emissions over the whole area need to be considered (CERC, 2003b).

Attempts to improve modelling accuracy were also made by incorporating a terrain file in the model to take account of the many hills and mountains around Chiang Mai. CERC checked this terrain file and confirmed that it was in the correct text file format [x, y (UTM coordinates) and z (height)] to be used for the model run, but when included in the model, the run would not proceed successfully. It appeared that either the program or the computer was not able to cope with the level of complexity introduced when the terrain file was included. Consequently, the run with the terrain file included had to be terminated after a 3-day run time without results. Therefore the runs for Phase III modelling were conducted without the terrain file.

Meteorological data are one of the required input data sets for running the ADMS-Urban model. It is not recommended to run the model for calm meteorological conditions, where the wind speed is less than 1m/s (CERC, 2002). Nevertheless, the model was run for 'calm conditions' for both February and August. For these months the wind speeds used for every line of meteorological data were automatically adjusted to 0.75m/s. This was so even though not all wind speeds were lower than 1m/s. For example, there were 744 hourly recorded wind speeds in August 2001 ranging from 0.12-7.46m/s, and of these over 350 wind speed values (approximately 47%) were greater than 1m/s. Since the model did not use exact wind speed rates, this may have affected the model calculations – particularly in relation to the distance of pollutant spread. Performance also depends upon the quality of the PC used to run the model (e.g. Pentium 4). Computer processing speed is critical. For the Chiang Mai input data, the model run-time was long when both 'gridded' (contour plots of pollutants) and 'specified' (pollutant concentrations at specific points) output options were selected. For example, the model run for February took approximately 24hrs to complete when both options were selected. The run times were shorter (1-1½hrs) when only the 'specified' output option was selected. Long run-times presented a particular problem in Chiang Mai because runs were often interrupted when electricity supply was lost due to heavy rain and storm events, particularly during April 2005.

In addition, the model may not be effective for air pollution modelling in Chiang Mai due to hourly wind speeds being typically low (mostly below 3m/s), especially during winter. This combined with a complex topography in the air modelling area (ranging from approximately 310m above sea level to over 1,500m), makes modelling with ADMS-Urban particularly difficult. The results of this study are consistent with the suggestions of Leuzzi (2002) and DEFRA (2000) who concluded that the ADMS-Urban model is not ideal for the prediction of pollutant concentrations in calm meteorological conditions. CERC admitted that the Gaussian distribution used for modelling starts to break down when wind speeds are near zero (pers. comm. Dr. Patricia Gilmour and Dr. Helen Higson). In contrast, CERC (2001) expected that the complex terrain module would allow for air flow and dispersion over hills and for roughness changes, including the effects of stratification. However, for this module to work properly, hills should have moderate slopes (less than 1 in 3) since very steep slopes (greater than 1 in 2) cause local reverse flows near the surface which cause the diffusion calculations to fail. The complex mountainous heights and slopes in Chiang Mai, combined with very low wind speeds challenge limitations of the model and are likely to result in prediction errors.

In addition to the above, transboundary pollution was not included among the ADMS-Urban input options, which may have lead to low predicted SO_2 concentrations. This is because the SO_2 emissions from sources outside Chiang Mai are significant (e.g. from a power plant station in Mae Moh, Lampang Province, where coal is mainly used in its production process). Yeo and Kim (2004) predicted the effects of regional SO_2 emission changes on the deposition of sulphur in East Asia in 2010, applying the RAINS-Asia model. The model estimated emission, transport and transformation of sulphur species (mainly SO_2) throughout China, Korea, Japan and SE Asian countries. This study showed that long-range transport of SO_2 species from China will also be likely to elevate SO_2 concentrations in Chiang Mai, where background SO_2 concentrations (excluding those from the power station) are normally very low. Although SO_2 is both highly reactive and soluble in water, and the average residence time in this oxidation state is only 24 hrs, its mean atmospheric lifetime against oxidation (in the presence of OH) can be up to 2 weeks (Jacob, 2000). Atmospheric residence times for sulphur compounds, which are typical of power plant pollutants, are rather uniformly distributed. Some pollutant molecules are deposited from the air quickly near the source, whereas others are deposited more slowly and thus further away (e.g. hundreds or even thousands of kilometers) through long-range transport processes, depending upon mixing, physical and chemical reactions and cloud processes including precipitation (National Academy of Science, 1983).

Some air modelling studies using ADMS-Urban, conducted in urban areas within large conurbations, such as London and HK SAR, have produced relatively accurate numerical results when the major sources of air pollution are local road traffic and industrial sources (The Corporation of London, 1999; Carruthers *et al.*, 2002; Huang *et al.*, 2002) (see Section 1.2.1). The results of this study suggest that it may not be the most appropriate model for use in Chiang Mai where major pollution sources are agricultural burning and forest fires in the surrounding areas. This problem is compounded by unfavorable weather conditions and complex local topography.

2.8 Conclusion

This study showed that the unavailability of detailed, local, source emission data makes atmospheric dispersion modelling difficult. This is particularly true in this case in relation to absent emission data for over 1,000 industrial sources (both point and area sources). These also include construction sites, road works and other road data for the larger area outside the Chiang Mai Comprehensive Urban Area. ADMS-Urban was also found to have some technical limitations for modelling air quality in Chiang Mai. These limitations, which explain its relative unsuitability for modelling air quality in Chiang Mai, include its inability to cope with; i) the very low hourly wind speeds occurring particularly in winter (December – February); ii) the complex topography (with extreme variations in height and slope in Chiang Mai Province); iii) some pollution inputs including those that arise from agricultural burning and forest fires. Furthermore, ADMS-Urban was designed primarily for use in urban areas at a local scale, and it lacks the capacity to deal with significant inputs of transboundary pollutants at the regional and international scales. Finally, the chemistry schemes applied in ADMS-Urban may not provide a realistic representation of atmospheric conditions for Chiang Mai, where there is strong ultraviolet radiation that results in lower NO_2 and higher O_3 concentrations in comparison to temperate atmospheres.

In spite of the limitations explained above, ADMS-Urban was found to be useful in terms of predicting relative pollution levels in different locations within Chiang Mai urban areas. Furthermore, the pollution maps produced were very useful in identifying where potential air-polluted areas are likely to be present. Such pollutant 'hot-spots' identified and portrayed on pollution maps can be an important tool for decision making in air quality management and for urban planning in Chiang Mai.

In conclusion, the use of ADMS-Urban for air quality modelling in Chiang Mai is not recommended, because the model did not perform well when tested. It follows that other air quality modelling systems should be investigated especially where these might be more suitable for predicting air quality when wind speeds are very low, when UV radiation levels and precipitation rates are high and when the topography is complex. The Models-3/CMAQ programme may be more appropriate for modelling air quality in Chiang Mai than ADMS-Urban because it allows for air pollutant emissions over spatial scales ranging from local to regional to trans-national and under various chemistry schemes.

CHAPTER 3

QUALITY OF LIFE QUESTIONNAIRE SURVEY CONDUCTED IN URBAN AND SUBURBAN AREAS OF CHIANG MAI

3.1 Introduction

The health survey was conducted between 31 May and 15 June 2003 in Chiang Mai, using a questionnaire (Appendix 6) which was translated and modified from an English version (Appendix 7) used by the London Borough of Barnet (LBB) and Middlesex University (MU) – acting as project leader and sub-contractor – respectively, for the EC Asia Urbs, MAQHUE project. The main objectives of this survey, as employed in Chiang Mai, were to investigate people's attitudes to air pollution and health in the air pollution probable 'hot-spots' (urban) and a 'non hot-spot' (suburban) area in Chiang Mai, as identified by the results of the Phase I air quality modelling exercise; and to statistically compare the results for these study areas (corresponding to Objective 1.2 iii of the research programme). The project summary is summarized in Table 3.1. The author was involved in assisting Dr. Phongtape Wiwatanadate (Chiang Mai University) with questionnaire translation (English/Thai), site selection, co-ordination and supervision of Chiang Mai University students who acted as interviewers (Table 3.2).

3.1.1 Concept of Quality of Life

Over the past two decades, the concept of quality of life (QoL) has been widely used in research and applied in many fields such as education, health, and social science (Schalock, 2004). The World Health Organization (WHO) defined QoL as "individuals' perceptions of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (WHO, 1996). QoL refers to a subjective evaluation embedded in a cultural, social and environmental context. The above definition focuses upon respondents' "perceived" quality of life. WHO (1996) divided QoL into four domains as follows;

- Domain I: Physical health (e.g. activities of daily living, dependence on medical substances and medical aids, morbidity, pain and discomfort, work capacity).
- Domain II: Psychological (e.g. self esteem, negative and positive feelings, religion or personal beliefs).
- Domain III: Social relationship (e.g. personal relationships; social support).
- Domain IV: Environment [e.g. financial resources, physical safety and security, health and social care (accessibility and quality), home environment, opportunities for acquiring new information and skills, recreational activities, physical environment (pollution/noise/traffic/climate), transport].

The Special Interest Research Group on Quality of Life (2000) suggested that QoL should be considered as a sensitizing concept (rather than a definitive one) which is relevant to public policy determination, evaluation of services, and development of innovative local, national and international programmes. This group also defined that a notion of QoL should be rooted in individual perceptions and values and capable of contributing to the identification of necessary supports and services. In addition, a QoL study should be holistic to the extent of recognising that different aspects of the individual's life may influence other aspects.

QoL is a concept that emerged around the mid-20th century and is usually applied to distinct areas (a neighbourhood, city, country). It contains many dimensions such as economic, social, cultural, environment (André *et al.*, 2001). Rogerson (1997) (cited by André *et al.*, 2001) defined "environmental quality of life" as a combination of the material and personal realms of life. The material realm consists of a series of goods, services and other attributes of the physical, economic and social environment in the geographic area where individuals live, and the personal realm is defined by individuals' characteristics and assessment of their own well-being and satisfaction. Rogerson (1997) attempted to reconcile the evaluation of quality of life with people's individual situations within different communities in Istanbul, Turkey. A questionnaire about satisfaction with day-to-day life was administered to 384 residents from 22 neighbourhoods. This questionnaire was based on 18 indicators ranked on a satisfaction scale of 1 to 4. It considered the following variables: shopping convenience, environmental pollution, level of education, cost of living, noise level, climate, job opportunities, transportation to work, crowding, relations with neighbours, housing conditions, parks, green space, health, recreational and sports opportunities, access to public transport and traffic congestion. The study described herein uses a similar concept of environmental QoL as employed in Rogerson's approach, and focuses on existing air quality as a key component.

Table 3.1 Project summary of the Quality of Life questionnaire survey conducted in urban and suburban areas of Chiang Mai (2003).

Title: Quality of life questionnaire survey conducted in urban and suburban areas of Chiang Mai, Thailand, 2003 **Subject Categories:** Environmental issue(s) – Air pollution **Depositor**: Department of Community Medicine, Chiang Mai University, Chiang Mai, Thailand **Principal Investigator(s):** Dr. Phongtape Wiwatanadate, Department of Community Medicine, Chiang Mai University (CMU) **Data Collector(s):** Department of Community Medicine, Chiang Mai University **Sponsor(s):** Environmental Office Region 1 (EO1), Chiang Mai **Involved Organizations:** EO1; CMU; Chiang Mai Office of Public Works and Town and Country Planning (CMOPT); Middlesex University, UK. **Background:** This study was conducted as part of Managing Air Quality and Health Impacts in the Urban Environment (MAQHUE) project, under the EC Asia Urbs programme. For application in Chiang Mai, a questionnaire designed for this project was modified and translated (into Thai) from the questionnaire used in the London Borough of Barnet, UK. The main objectives of the Chiang Mai survey were to investigate people's attitudes to air pollution and health in the air pollution 'hot-spots' (urban) and a 'non hot-spot' (suburban) area, as identified by the results of air quality modelling; and to statistically compare the results for the study areas.
Main Topics: Three opening questions were asked prior to a full interview: i) age of respondent, ii) residential address and iii) residential duration in selected study area. The interview continued when the respondent's age was 15 or over and the residential duration was 1 year or over. Respondents were then asked about: i) general personal data (e.g. age, sex, marital status); ii) life style (e.g. smoking, diet, alcohol intake, stress (and cause of stress), means of transport; iii) housing conditions (e.g. type of house, traffic condition and sources of air pollution in residential area); iv) air quality information (e.g. air quality information ever obtained, level of interest, means of information distribution preferred). All respondents were asked the same questions as structured in the questionnaire.
Coverage: Urban areas were selected on the basis of ADMS-Urban (atmospheric dispersion system) identified pollution 'hot-spots'. Fifteen is the recognised age of adulthood in Thailand. ***Dates of Fieldwork:***31 May-15 June 2003 ***Country:*** Thailand ***Province:*** Chiang Mai ***Spatial Units:*** Urban and suburban districts ***Observation Units:*** Individuals ***Type of Data:*** Numerical (e.g. age, time duration)and categorical data; Individual (micro) level ***Location of Units of Observation:*** Provincial ***Population:*** Adults aged 15 and over in Chiang Mai Province **Methodology:** ***Time Dimensions:*** Cross-sectional study (May – June 2003) ***Sampling Procedures:*** Judgment sampling ***Number of Respondents:*** 2000 (target), 2000 (obtained) ***Method of Data Collection:*** Personal interview
Language(s): ***Questionnaire:*** Thai ***Interview:*** Thai ***Written report:*** English. The Thai questionnaire was translated into English by the author for presenting in this PhD thesis. The original questionnaire was constructed by Middlesex University, UK.
Note: 300 completed questionnaires (out of 2,000 administered) were supplied to Ms. Kanyawat Sriyaraj for preliminary statistical analysis and inclusion in the report to EC. Further analysis in study design and statistics was conducted as part of Ms. Sriyaraj's PhD project (Local Air Quality Management and Health Impacts of Air Pollution in Chiang Mai, Thailand). The other 1,700 completed questionnaires were deposited at the Department of Community Medicine, Chiang Mai).

Table 3.2 List of tasks and responsible persons conducting the Quality of Life questionnaire survey conducted in Chiang Mai.

Tasks	Responsible/conducted by
1. Original questionnaire design, used in London Borough of Barnet, UK	Ms. Nuria Machin, Middlesex University
2. Translation of the English questionnaire, developed by MU for administering in LBB, into Thai.	Ms. Kanyawat Sriyaraj
3. Modification of the questionnaire	Dr. Phongtape Wiwatanadate, CMU
4. Site selection (as results of ADMS-Urban identified pollution 'hot-spots'	Ms. Kanyawat Sriyaraj and Mr. Pichat Ouiyanukoon, CMOTP
5. Distribution and administration of questionnaire	Dr. Wiwatanadate's students, Department of Community Medicine, CMU
6. Data transfer from the completed questionnaires (n=300) to SPSS programme	Ms. Kanyawat Sriyaraj
7. Statistical analysis	Ms. Kanyawat Sriyaraj
8. Summary of results and reporting	Ms. Kanyawat Sriyaraj

3.1.2 Questionnaire Design

A questionnaire survey is a form of statistical survey usually handed out in paper form to gather information. Questionnaires offer an objective means of collecting information about people's knowledge, beliefs, attitudes and behavior (Oppenheim, 1992 and Sapsford, 1999 cited by Boynton and Greenhalgh, 2004). They are normally used as research instruments in cross-sectional studies, conducted at a single point in time, or in epidemiological studies. Sound questionnaire research should be well designed, well-managed and non-discriminatory, which contributes to a generalisable evidence base (Boynton and Greenhalgh, 2004). A valid questionnaire measures what it claims to measure. A questionnaire developed at a different time or in a different country or cultural context may not represent a valid measure in another situation.

A questionnaire research study generally consists of the following processes: (i) Decide the aims of the survey; (ii) Design the survey (including the questionnaire); (iii) Pilot study and preliminary data analysis; (iv) Fieldwork and administration; (v) Data processing and analysis; (vi) Survey report (Jarrett, 2004). The process of questionnaire design was also summarized into 5 stages by Jarrett (2004): (i) Decide what information is required; (ii) Draft questions to elicit that information; (iii) Put them into a meaningful order and format; (iv) Pre-test the questionnaire (piloting); (v) Go back to Step (i), and continue until the questionnaire is perfect. A good question should be consistently understood by all respondents and they should understand the question in the way intended by the investigator. Jarrett (2004) recommended that questionnaires should be as brief, clear and simple as possible, while covering all areas on which information is required. Normally, a question should not be more than 20 words long. Common forms of administering a questionnaire are summarized in Table 3.3. Before conducting a full questionnaire survey, a pilot survey should be conducted to investigate whether any questions need to be changed or omitted. A pilot study is the pre-testing of a particular research instrument or questionnaire in this context (van Teijlingen and Hundley, 2001). Although piloting does not guarantee the success of a full-scale study or survey, it helps to assess the feasibility of the study and test the adequacy of research instruments. Piloting a questionnaire can be conducted on a small group of volunteers, who are as similar as possible to the target population. The results of pilot surveys should be statistically analysed and also included in the survey report (van Teijlingen and Hundley, 2001). Pilot study procedures to improve the validity of a questionnaire are summarized in Table 3.4.

Table 3.3 Common forms of questionnaire administration

Forms of questionnaire administration	Detail
Personal (face-to-face) interview	Normally regarded as the most reliable form of questionnaire survey, but it is time-consuming and it can be expensive if trained interviewers are used. Some people may be unwilling to answer personal questions.
Telephone interview	Cheaper and easier to conduct than personal interviews. The questions should not be as complex as in personal interview questionnaires. Also, interviewers are easier to supervise. Some people may be unwilling to answer personal questions.
Self-completion (self-administered or mail questionnaire)	The most common form of questionnaire research because it is comparatively cheap. However, many people may fail to return the questionnaire which can result in a low response rate. Careful instructions need to be given about how to complete the form. Respondents are more willing to answer personal questions particularly if anonymity is assures Non-respondents should be followed up (e.g. sending out a second copy of the questionnaire).

Source: Jarrett (2004)

Table 3.4 Pilot study procedures to improve the validity of a questionnaire

Pilot study procedures	
(i)	Administer the questionnaire to pilot subjects in exactly the same way as it will be administered in the main study.
(ii)	Ask the subjects for feedback to identify ambiguities and difficult questions.
(iii)	Record the time taken to complete the questionnaire and decide whether it is reasonable.
(iv)	Discard all unnecessary, difficult or ambiguous questions.
(v)	Assess whether each question gives an adequate range of responses.
(vi)	Establish that replies can be interpreted in terms of the information that is required.
(vii)	Check that all questions are answered.
(viii)	Re-word or re-scale any questions that are not answered as expected.
(ix)	Shorten, revise and, if possible, pilot again.

Source: Peat *et al.*, 2002

Table 3.5 summarises advantages and disadvantages of open- and closed-ended questionnaires. Closed-ended questionnaires are those in which subjects choose between a set range of answers, whereas an open-ended design allows the composition of individual responses. Closed-ended questionnaire design enables researchers to produce aggregated data quickly but the possible answers are set by the researchers, not the respondents and this may lower the richness of potential responses. Closed-ended items may cause frustration if all potential responses have not been considered (Houtkoop-Steenstra, 2000 cited by Boynton and Greenhaigh, 2004). In this Chiang Mai study, most of the questions in the questionnaire are closed-ended. However, in order to avoid any frustration if all possible responses were not included in the choices provided, some questions allow respondents to write their own answers by including, as a last option, 'please specify' with a writing space. These are called semi-open questions and are similar to closed-ended questions. A semi-open question can be used where only one answer should be ticked, but where the investigator does not know all the possible answers to list individually, so what are believed to be the most likely answers are provided as choices (Jarrett, 2004).

Table 3.5 Advantages and disadvantages of open- and closed-ended questions

Type of questions	Advantages	Disadvantages
Closed-ended	• Appear easy and quick to complete (which may encourage respondents to fill them in). • Respondents do not have to compose an answer. • Socially less desirable responses can be included as an option. • Responses are usually clear and complete. • Easy to standardize, code and analyse. • Suitable for either self-completion or completion with a researcher's assistance	• Depend upon respondents' understanding of concepts. • Respondents may guess or tick any response at random. • Either respondents or researchers may make errors (e.g. tick the wrong box by mistake) • Do not allow respondents to expand on their responses or offer alternative views.
Open-ended	• Allow for respondents' creativity and free expression. • Capture responses, feeling and ideas that researchers may not have foreseen. • Respondents may write as much or as little as they wish.	• Take longer to complete (which can dissuade people from responding) • Responses can be extremely laborious (and expensive) to analyse. Coding and interpretation needed. • If handwriting is not clear, data are lost. • Rely on respondents to be expressive and have writing skills.

Source: Boynton and Greenhalgh (2004).

To administer a questionnaire for every member of a population is impossible (e.g. due to budget and time constraints). Thus, sampling is conducted in order to select individuals that are representative of the population of interest (Jarrett, 2004). Table 3.6 summarizes sampling methods that have been used in this field, from simple random sampling to non-probability sampling. In the administration of a questionnaire, the respondents should be assured of confidentiality and anonymity. Confidentiality is not required where the questionnaire is made completely anonymous (e.g. no name code or identifying in the questionnaire). In general, people will be more willing to complete the questionnaire if they can see that they cannot be identified; however, this is not always the case, Questionnaires need not always be anonymous, particularly in surveys of organizations rather than individuals (e.g. asking about environmental policies) (Jarrett, 2004). Boynton (2004) stated that the choice of how to administer a questionnaire was often made based on the grounds of convenience or cost, however, scientific and ethical considerations should include (i) the needs and preferences of participants, who should understand what is required of them, be interested and cooperative throughout the completion, be asked the right questions and have their responses recorded accurately, and receive appropriate support both during and after completing the questionnaire; (ii) the skills and resources available to the research team; (iii) the nature of the study (e.g. short-term feasibility projects or large scale surveys).

Table 3.6 Detail of sampling methods generally applied in questionnaire surveys

Sampling methods	
(i) Simple random sampling	From a population or large group of individuals, a simple random sample (of size n) is a sample of n members of the population selected in such a way that all possible samples of size n have the same probability of being selected. All the members of a population are listed 1,2,3,...,N (where N is the population size). A list of random numbers can be obtained in the form of a table (available in books of statistical tables) or from a random number generator (e.g. Microsoft Excel software) (Jarrett, 2004).
(ii) Stratified random sampling	A method of random sampling from a population divided into strata (relatively uniform subsets of a population) (Jarrett, 2004). Advantages of stratified sampling include: i) it enables focus on important subpopulations while ignoring irrelevant ones; ii) improves the accuracy of estimation; iii) efficient; iv) sampling equal numbers from strata varying widely in size may be used to test differences between strata. However, it can be difficult to select relevant stratification variables (Wikipedia, 2006).
(iii) Cluster sampling	The total population is divided into groups or clusters and then a random sampling technique is then applied on any relevant clusters to select which clusters to include in the study (Wikipedia, 2006).
(iv) Quota sampling	In this sampling, the population is first segmented into mutually exclusive sub-groups, as in stratified sampling. Then judgment is used to select the subjects or units from each segment based on a specified proportion. In this kind of sampling, the selection of the sample is non-random (Wikipedia, 2006).
(v) Non-probability sampling	
• Convenience sampling	Members of the population are chosen based on their relative ease of access (e.g. friends, colleagues) (Wikipedia, 2006).
• Snowball sampling	The first respondent refers a friend and the friend also refers a friend, etc. (Wikipedia, 2006)
• Ad hoc quotas	A quota is established (e.g. 65% women) and researchers are free to choose any respondent to meet the quota (Wikipedia, 2006).
• Judgment (or purposive) sampling	The researchers choose a sample based on who they think would be appropriate for the study (Wikipedia, 2006).

3.2 Methodology

The methodology of the questionnaire survey conducted in urban and suburban areas of Chiang Mai is summarised as follows;

3.2.1 Questionnaire design

The original questionnaire, designed by Middlesex University (MU) to administer in London Borough of Barnet (LBB), as part of the MAQHUE project, aimed to investigate the relative importance of air pollution compared to other influences on the health and quality-of-life indicators of the target population. It consists of four sections as follows;

- Section 1 – Physical environment. This section has two sub-sections – housing conditions (type of accommodation, indoor air pollution factors, type of heating, level of traffic in immediate neighbourhood) and occupational description (occupation, monthly income, car ownership);
- Section 2 – Personal information (age, sex, ethnic group, religion, highest educational level);
- Section 3 – Life style (exercise, smoking, alcohol intake, diet, stress (and causes of stress), illnesses, life satisfaction and access to health care);
- Section 4 – Air quality information (personal interest, regularity of air quality information access, means of traveling, level and source of air pollution).

Different types of questions were used in the LBB questionnaires as follows;

- Scaled questions – responses are graded on a continuum such as 5-point or 10-point scale or Likert scale that is a scaling method to measure either positive and negative response to a statement (normally provided with options from "strongly agree" through to "strongly disagree"); and rank-order scale (e.g. a respondent is presented with several items simultaneously and asked to rank them) (Boynton and Greenhalgh, 2004; Wikipedia, 2006).
- Closed ended questions – Most scales are closed ended. The questions with "yes and no" answers are called dichotomous questions, for example, "Do you smoke?" (Section 3, Question 27). The questions with several choices for respondents to choose are called multiple choice, for example, "How would you describe the level of traffic in your street?" (Section 1, Question 8) and there were five choices as follows; None; Light; Moderate; Busy and Very Busy.

- Open-ended questions – respondents are free to write their own answers. These include factual questions, for instance, "How many adults live at your address?" (Section 1, Question 4), and questions asking about opinion or attitude, such as, "Is there any thing in your home that you think might affect your health?" (Section 1, Question 6). In addtion, questions asking about reasons are normally open-ended, for example, "If (you are) not (interested in getting air quality information about you area), why not? (Section 4, Question 37).

However, it was considered by Dr. Wiwatanadate that the LBB questionnaire was too long (48 questions in total – 41 main questions and 7 minor questions). Whilst the Thai questionnaire was designed to be as consistent as possible with the study used in LBB, there were some changes made to it to suit Chiang Mai situations and Thai culture. Table 3.7 summarises the structure and questions of the original LBB questionnaire. Most of the questions remained as original but some were modified or excluded from the Thai questionnaire. Both new and modified elements are summarized in Table 3.8. For instance, a question concerning type of heating was excluded due to differences in climate but a question concerning the use of air conditioners was added instead. A personal question about household income was also excluded from the Chiang Mai questionnaire because many people in Chiang Mai, such as farmers and construction workers, have low incomes and they may have been offended by the question – affecting their willingness to co-operate with the study. Therefore, the socio-economic status among Chiang Mai respondents was assessed from answers to the question concerning the highest level of education – rather than household income. In addition, the alcohol unit system as used in Britain is not used in Thailand. The question about alcohol consumption was simplified to 'how often do you drink alcohol?' (never, sometimes or everyday). The questions regarding the GPs (e.g., waiting duration for an appointment the GPs) were also excluded in the Chiang Mai questionnaire because of the differences in accessing health care between UK and Thailand. In Chiang Mai, both private and public hospitals including public health service centres and private clinics are widely available and patients do not normally have to make an appointment. The modified version for the survey in Chiang Mai is summarized in Tables 3.9 and 3.10. There are 33 questions in total (4 sections).

Table 3.7 Structure and questions of the original questionnaire employed in London Borough of Barnet, UK. Most of the questions remained in use but some were modified or excluded from the Thai questionnaire.

Questions	Equivalent	Excluded	Modified
Section I: Physical environment			
A. Housing conditions			
1. Please give your full postcode of your present address [OQ]	✓		
2. How long have you lived at your present address? [CQ]	✓		
3. Is your accommodation? [SoQ]	✓		
4. How many adults live at your address? [OQ]		✓	
5. How many children live at your address? [OQ]		✓	
6. Is there any thing in your home that you think might affect your health? [OQ]	✓		
7. Type of heating in your home [CQ]		✓	
8. How would you describe the level of traffic in your street? [CQ]	✓		
B. Occupational description			
9. How many wage earners are there in your household? [OQ]		✓	
10. Occupation [SoQ]		✓	
11. If employed, please state your and/ or your partner's occupation [OP]		✓	
12. How long have you worked at your present job? [CQ]		✓	
13. If unemployed, a) Do you receive any benefits [Y/N]; b) How long have you been unemployed [CQ]		✓	
14. On which of the following does your (household disposable) monthly income fall (after tax / national insurance deductions)? [CQ]		✓	
15. Do you/your partner own a car? [Y/N]		✓	
Section II: Yourself			
16. Are you: female or male? [CQ]	✓		
17. Can you please indicate what age group you belong to? [CQ]	✓		
18. Please state your country of birth [OQ]			✓
19. If UK is not a place of birth, how long have you lived in this country? [OQ]			✓
20. How would you best described yourself (ethnic group) [SQ]		✓	
21. What is your first language? [OP]		✓	
22. What is your religion? [OP]	✓		
23. What highest educational qualifications or equivalent do you have? [SQ]	✓		
Section III: Your lifestyle			
24. Do you do any of the following physical activities regularly? [SoQ]	✓		
25. How many units of alcohol do you drink per week? [OQ]			✓
26. Do you think you eat fresh fruit and vegetables regularly? [Y/N]	✓		
27. Do you smoke? [Y/N]	✓		
a) If yes, how many cigarettes per day? [OQ]	✓		
b) If yes, how long have you been a smoker? [OQ]	✓		
c) If no, are you an ex-smoker? [Y/N]	✓		
d) Does anyone smoke inside your home environment? [Y/N]	✓		
e) Does anyone smoke inside your work environment? [Y/N]	✓		
28. Do you feel happy – contented with your life? [CQ]	✓		
29. What are the main causes you feel cause your stress? [OQ]	✓		
30. In your view, what are the most important outside effects which influence your health [SQ]	✓		
31. Have you suffered from any of the following illnesses over the past 12 months? [CQ]	✓		
32. Do you have access to private health insurance? [Y/N]			✓
33. How long, on average, do you wait for an appointment at your GP surgery? [OQ]		✓	
34. Is your GP surgery within 2 miles of your home? [Y/N]		✓	
35. Do you suffer from any illnesses/conditions/physical impairments? [Y/N, and SQ]	✓		
Section IV: Air quality information			
36. Do you check out Air Quality Information (AQI)? [CQ]		✓	
37. How interest are you getting the following AQI about your area? [SQ] If not, why not….[OQ]	✓		
38. If you wished to access AQ what would be your preferred source? [CQ&OP,RS]	✓		
39. How do you travel to work (or between the places) [SoQ]	✓		
40. Do you think the level of air pollution in your area is? [CQ]	✓		
41. What do you think is the main source of air pollution in your area? [CQ]	✓		

Note: CQ = Closed-ended question; OQ = Open-ended question; Y/N = Closed-ended question with yes/no answers; SoQ = Semi-open question; SQ = Scaled question (e.g. 5-point scale or Likert scale); RS = Rank order scale

Table 3.8 Summary of new and modified questions in the Quality of Life survey in Chiang Mai

Modified questions	
Original version	***Thai version***
i) Please state your country of birth [OQ] ii) If UK is not your place of birth, how long have you lived in this country? [OQ] iii) How many units of alcohol do you drink per week? [OQ] iv) Do you have access to private health insurance? [Y/N]	i) Please state province of birth [OQ] ii) How long have you lived in Chiang Mai? [OQ] iii) How often do you drink alcohol? (Never; Sometimes; Everyday) [CQ] iv) Which health insurance scheme do you have? (None; 30 baht Universal Health Scheme[a]; Private health insurance; Reimbursable from Government[b]; Social Security Scheme[c]; Other, please specify.....) [SoQ]
New questions	
	i) Marital status (Single; Married; Widow; Divorced/separated) [CQ] ii) How often do you experience stress? (Never; Sometimes; Most of the time) [CQ] iii) Do you think you follow a healthy diet? (Yes/No) [Y/N] iv) Have you ever received air quality information? (Never; Occasionally; Often) [CQ]

Note: CQ = Closed-ended question; OQ = Open-ended question; Y/N = Closed-ended question with yes/no answers; SoQ = Semi-open question; SQ = Scaled question (e.g. 5-point scale or Likert scale); RS = Rank order scale

[a]30 baht Universal Health Scheme is the universal health coverage scheme in Thailand, for all Thai people to have an equal right to access health services (Sreshthaputra and Indaratna, 2001); [b]Civil Servants Medical Benefit Scheme enables Thai civil servants to reimburse their health care expenditures (and their dependants') from the Government. [c]Social Security Scheme, introduced in 1990s, protects workers (employees) and is mandatory for all private firms (Towse *et al.*, 2004).

Boynton *et al.* (2004) commented that indigenous Western people were generally more familiar with rating scales, and indicating preferences or choices, than most other groups. For this reason, a question with 5-point scales, such as Question 37 in Section IV of the original LBB questionnaire was modified from a 5-point scaled to 3-point scaled question (Question 4.2), which was generally easier for Thai people to comprehend. For the Chiang Mai questionnaire, there were 4 main sections as follows;

- Section 1 consisted of 11 questions concerning personal information: address, sex, age, religion, marital status, highest level of education, birthplace, duration of residence both in Chiang Mai and the current address, health insurance schemes and illnesses.
- Section 2 contained 15 questions concerning lifestyle: sport, diet, alcohol intake, cigarette smoking [and environmental tobacco smoke (ETS) exposure at home and work], positive and negative feelings (happiness/stress), causes of stress, outside effects influencing health, air-pollution-related diseases and means of transport.
- Section 3 consisted of 5 questions focusing on housing conditions as follows: type of accommodation, indoor factors affecting health, traffic (near the accommodation), level and source of outdoor air pollution.

- Section 4 comprised 3 questions regarding air quality information as follows: whether the information was ever received, level of interest in air quality information and the preferred media of accessing such information.

Table 3.9 List of questions and codes in the questionnaire used for the Quality of Life questionnaire survey conducted in urban and suburban areas in Chiang Mai (Sections I and II)

Questions	Codes
Section I: Personal information	
1.1 Full address [OQ]	
Village	MOO
Road	ROAD
Sub-district	TAMBON
District	DISTRICT
1.2 Sex (Male or female) [CQ]	SEX
1.3 Age (years) [OQ]	AGE
1.4 Religion [SoQ]	RELIGION
1.5 Marital status [CQ]	MARITAL
1.6 Highest level of education [SoQ]	EDUCATE
1.7 Birthplace (province) [OQ]	BIRTHPLC
1.8 How long have you lived in Chiang Mai? (years) [OQ]	CMSTAY
1.9 How long have you lived at the above address? (years) [OQ]	HOMESTAY
1.10 Which health insurance scheme do you have? [SoQ]	HTHINSUR
1.11 Do you suffer from any illnesses, conditions, or physical impairments? [Y/N & SoQ]	DISEASE
Section II: Lifestyle	
2.1 Do you do any of the following activities regularly? [SoQ]	SPORT
2.2 Do you think you follow a healthy diet? [Y/N]	FOOD
2.3 How often do you drink alcohol? [CQ]	ALCOHOL
2.4 How often do you eat fresh fruit and vegetables? [CQ]	FRUIT
2.5 Do you smoke? [CQ]	SMOKE
2.6 If yes, how many cigarettes per day? [OQ]	CIGARET
2.7 If yes, how long have you been a smoker? [OQ]	SMOKEDUR
2.8 Does any member of your family smoke in your home environment? [Y/N]	MEMBSMOK
2.9 Does anyone smoke in your work environment? [Y/N]	WORKSMOK
2.10 Do you think you are happy? [CQ]	HAPPY
2.11 How often do you experience stress? [CQ]	STRESS
2.12 What are the main causes of your stress? [SoQ]	STRECAUS
2.13 What are the most important outside effects which influence your health? [RS& SoQ]	
Accident	HACCIDENT
Air pollution	HPOLLUTA
Noise	HNOISE
Poor diet	HFOOD
Poor housing	HHOUSE
Smoking	HSMOKE
Stress	HSTRESS
Too little exercise	HEXERCIS
Violent crime	HCRIME
Poverty	HPOVERTY
Other, please state.......	
2.14 Have you suffered from any of the following over the past 12 months? [Y/N]	
Asthma	ASTHMA
Dry eyes/eye irritation	DRYEYE
Migraine	MIGRAINE
Chest infection (bronchitis, pneumonia)	LRI
Respiratory infection (cold, flu)	URI
Other allergic reactions (eczema, hay fever, etc.)	ECZEMA
2.15 How do you normally travel in Chiang Mai? [SoQ]	TRANSPOR

Note: CQ = Close-ended question; OQ = Open-ended question; Y/N = Closed-ended question with yes/no answers; SoQ = Semi-open question; SQ = Scaled question (e.g. 5-point scale or Likert scale); RS = Rank order scale

Table 3.10 List of questions and codes in the questionnaire used for the Quality of Life questionnaire survey conducted in urban and suburban areas in Chiang Mai (Sections III and IV)

Questions	Codes
Section III: Housing conditions	
3.1 Type of accommodation? [SoQ]	HOUSETYPE
3.2 Are there any factors in your home that might affect your health? [CQ]	
Dampness	DAMP
Lack of air conditioners/ air cleaners	AIRCON
Closed house/ no air circulation	VENTILA
Dust	HOMEDUST
Chemicals	CHEMICAL
Cooking	COOKING
3.3 How is the level of traffic near your house? [CQ]	TRAFFIC
3.4 How would you describe the level of air pollution in your area? [CQ]	POLLEVEL
3.5 What is the main source of air pollution in your area? [SoQ]	POLSOURC
Section IV: Air quality information	
4.1 Have you ever received air quality information? [CQ]	AQINFO
4.2 How interested are you in receiving the following air quality information? [SQ]	
Source of air pollution	AQTYPE
Different effects of air pollution	AQIMPACT
How to avoid air pollution	AQAVOID
What you can do about reducing air pollution	AQMITIGA
A forecast of tomorrow's air quality	AQFORCAS
The current air quality (now)	AQNOW
Air quality in previous days, weeks or years	AQPAST

Note: CQ = Close-ended question; OQ = Open-ended question; Y/N = Closed-ended question with yes/no answers; SoQ = Semi-open question; SQ = Scaled question (e.g. 5-point scale or Likert scale); RS = Rank order scale

3.2.2 Sampling and Piloting

From the results of Phase I of atmospheric dispersion modelling in Chiang Mai, the identified pollution 'hot-spots' were proposed to Dr. Wiwatanadate for use as the study areas for the questionnaire survey (see Table 2.9), and a non 'hot-spot' was also included (San Pooleui, Doi Saket District). San Pooleui is a suburban sub-district and was used as a control site for comparison with the urban districts. The funding for the questionnaire survey in Chiang Mai was the responsibility of EO1 and both EO1 and CMU set a quota of 2000 for the total sample size. Three districts were included in the survey: (i) Muang (City) (n = 1,600); (ii) Saraphi (n = 300); (iii) Doi Saket (n = 100). Initial site selection was based upon ADMS-Urban modelling results and the residents, whose accommodation was located on or near busy commercial roads (as listed in Table 2.9), were the targets of the survey.

The pilot survey was conducted on the first day of the field survey. All interviewers reported that the respondents had no difficulties in comprehending the questionnaire. However, the interviewers who were responsible for the survey in Muang district did not think that the number of respondents in the district would meet the quota of 1600 due to the target population living along certain roads being too small (e.g. Witchayanon, Maneenoparat, Sriphum). Dr. Wiwatanadate, Mr. Pichat Ouiyanukoon (CMOPT) and the author agreed that other major commercial and tourism areas in the city centre should also be considered and included in the survey even though ADMS-Urban did not identify them as pollution 'hot-spots'. Other busy roads in Muang District which were later included in the survey included Tha Pae, Chang Klan, Hussadisewi, Kampangdin, Charoen Muang and Chiang Mai-Sankampang). Therefore, a judgment sampling process, which is one of the non-probability sampling methods, was applied to select respondents in this survey (see Table 3.6).

The completed questionnaires from the pilot study were not analysed separately but were analysed with the data collected for the main survey. It was not possible to exclude the pilot-study respondents because to do so would result in too small a sample in the main study (van Teijlingen and Hundley, 2001). Ideally, a pilot study should have been conducted as in the process of Peat *et al.* (2002). However, EO1 received limited funding and the proposed research proposal may not have included a budget for a pilot survey. Moreover, CMU did not receive funds allocated by the EC for this study.

3.2.3 Distribution and administration

Personal interviews were undertaken with all of the respondents by Dr. Wiwatanadate's students from the Department of Community Medicine, CMU. All respondents (n=2000) were chosen with consideration of their age, duration of residence in Chiang Mai, and duration of stay in the study areas. The interviewers first introduced themselves and the objectives of the questionnaire survey and then asked politely for their co-operation to complete the questionnaire. Each respondent was asked three opening questions about their age, address and duration of residence at the address. The minimum age accepted for the survey was 15 – equivalent to the official age of adulthood in Thailand; and the minimum acceptable duration of residence in the study areas was 1 year. A 1-year duration was considered long enough for residents to feel attached to the local community and understand its environment, particularly in relation to local air pollution. If the preliminary answers did not meet these three conditions, the interview was discontinued. The respondents in the selected sites were approached door-to-door by the interviewers.

There were two methods of questionnaire administration in the survey. First, the interviewers read out each question (and the choices provided with the question) and recorded the answers given by the respondents, starting from the first question in Section 1 to the last question in Section 4. This interview method took 5-10 minutes to complete. Secondly, some respondents wished to complete the questionnaire by themselves, in the presence of the interviewer, who was prepared to reply if the respondents did not understand any questions. The latter method took twice as long (approximately 10-20 minutes). However, most of the respondents (approximately 80%) preferred the first method (pers. comm. Ms. Viranlapach Sunhinnapongse, one of the interviewers). Ms. Sunhinnapongse also observed that the respondents claiming higher levels of education (e.g. college or university degrees) preferred to complete the questionnaire by themselves.

3.2.4 Coding and analysis

Three hundred out of 2000 completed questionnaires were supplied to the author (by Dr. Wiwatanadate) for statistical analysis. The author specifically requested the completed questionnaires from Saraphi District and Poi Luang Junction (in Muang District) because these were ADMS-Urban identified pollution ‘hot-spots’; with San Pooleui (in Doi Saket District) to be used as a control (Table 3.11). It is noted that the author was allowed to analyse only 300 completed questionnaires. The other 1700 questionnaires were deposited at the Department of Community Medicine, CMU as the funding for this particular questionnaire survey in Chiang Mai was not obtained from the MAQHUE project.

Table 3.11 Summary of the number of the completed questionnaires from the questionnaire survey in Chiang Mai, and the number of the questionnaires allocated for used in this PhD project

Study areas	No. of completed questionnaire in each area	No. of completed questionnaire used for analysis*	Percent
Muang (City) District	1,600	100	6.25
Saraphi District	300	100	33.33
Doi Saket District	100	100	100
Total	2,000	300	

Note: *For reporting to the European Commission, the funding agency of MAQHUE project, and for further statistical analysis for Ms. Kanyawat Sriyaraj’s PhD project.

For each questionnaire, the selected answers were coded manually following the names pre-coded on the questionnaire (Tables 3.9 and 3.10), and then the data were transferred to the “Statistical Package for the Social Sciences” (SPSS) programme (version 11) for analysis. The Pearson χ^2 (chi-squared) test and Fisher’s exact test were applied to the data in order to investigate the significance of any noted differences in each variable by type of study area (urban vs. suburban). Both tests can be used to test statistical significance in the analysis of nominal data that are qualitative or categorical (e.g. yes/no, male/female). Both tests are used to examine the significance of the association between two or more variables in a table that contains independent data. However, the Pearson χ^2 test is not suitable for use when sample sizes are small (i.e. when the values in any of the cells of the table are below 5) or the data are very unequally distributed among the cells of the table. In this case, the Fisher's exact test should be used with data in 2x2 tables (or more rows or columns) (Wikipedia, 2006). In addtion, the Fisher's exact test provides an exact test that removes any possible problem with expected frequencies less than 5, whereas the Pearson χ^2 test is an approximation, which is valid only for reasonably large samples (pers. comm. Dr. David Jarrett). The significance level employed was p=0.05. In each case the null hypothesis was that there was no difference between the responses of the urban and suburban area subjects.

3.3 Site Descriptions

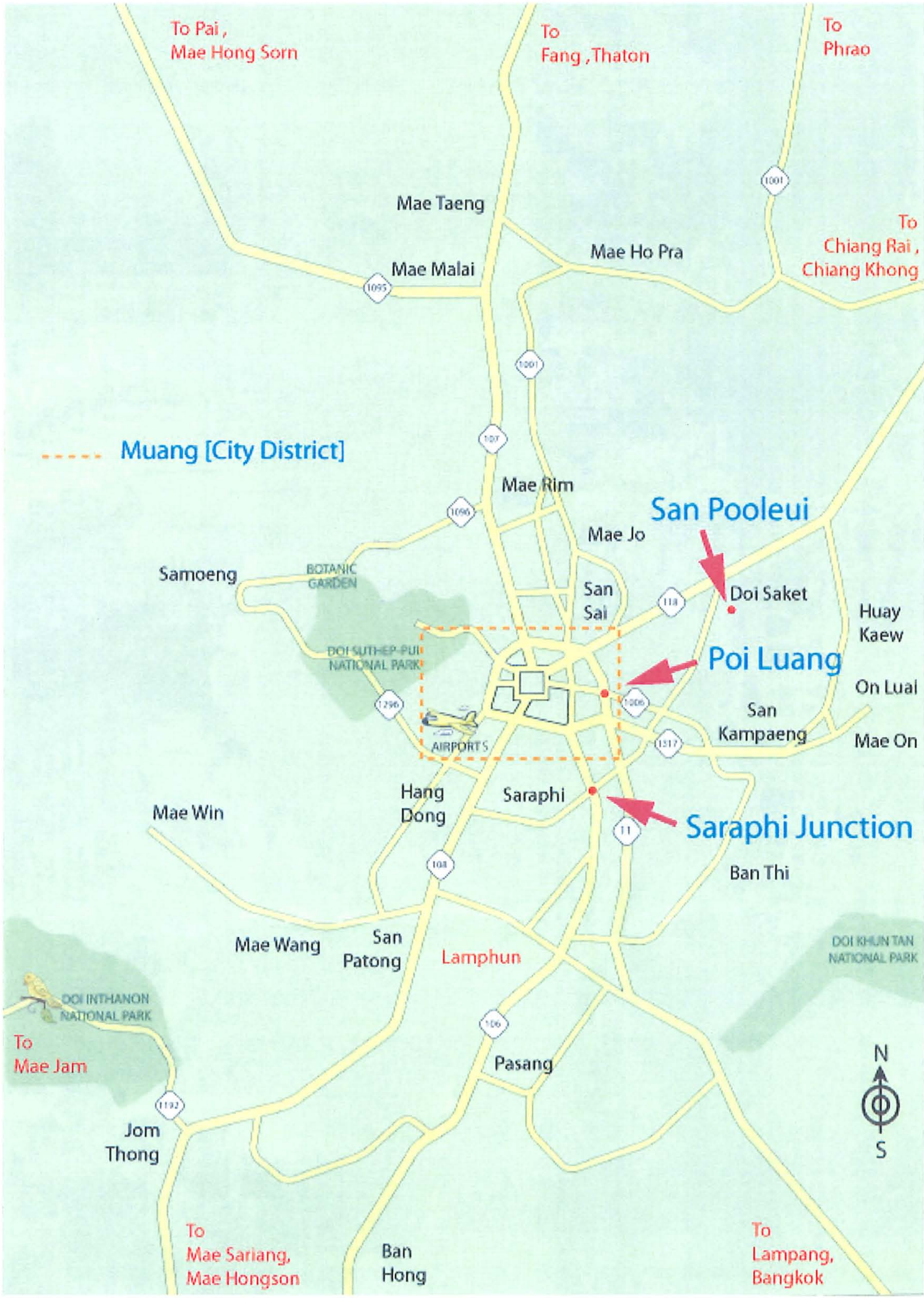
The survey areas for which questionnaire data were analysed were 2 air pollution 'hot-spots' in urban areas (Saraphi and Poi Luang Junctions in Saraphi District and Muang District, respectively) and 1 'non hot-spot' control area (San Pooluei Sub-district, Doi Saket District), which is an agricultural area, located in the northeast of Chiang Mai province (see Figure 3.1).

3.3.1 Saraphi Junction

Saraphi Junction, situated in the southeast of Chiang Mai, is a junction of Highway 106 and a public road. This area is a busy commercial and residential area and is characterised by shop-houses along the busy narrow 2-way road. People normally live in the second or third floor of a shop-house and work in the shop area on the ground floor. Other activities in the area include petrol stations, a police station, temples, and schools (Figure 3.2).

3.3.2 Poi Luang Junction

Poi Luang Junction is located in the Municipality area and is near the city center where Highway 1006 meets Highway 11. It is one of main commercial areas of Chiang Mai and has a high population density. Banks, petrol stations, offices, schools and a department store are all situated in this area. Shop-houses are also common and residential houses are located both in and around housing estates which are typically located slightly further away from main roads than are shop-houses (Figure 3.3).



Modified from Chiang Mai Tourist Map, Chiang Mai Information Centre (2003)

Figure 3.1 Study areas for the Quality of Life Questionnaire Survey Conducted in Urban and Suburban Areas in Chiang Mai.

Figure 3.2 Saraphi Junction, Saraphi District

Figure 3.3 Poi Luang Junction, Muang District

Figure 3.4 San Pooleui, Doi Saket District

3.3.3 San Pooleui

San Pooleui is an agricultural area situated in Doi Saket district, northeast of Chiang Mai province (Figure 3.4). Rice paddy fields are one of the main features of San Pooleui. The farmers in this area do not burn rice stalks and ploughing to remove such stalks is the normal practice.

3.4 Results

The results of statistical analysis are summarised in 4 parts following the structure of the questionnaire: Part 1 – personal information; Part 2 – lifestyle; Part 3 – housing conditions, and Part 4 – air quality information (Tables 3.12 – 3.22).

3.4.1 Part 1 – Personal Information

The age range and average age of respondents was 15 – 89 years and 45 years, respectively. The range and average of duration of living at the present address was 1 – 89 years and 30.2 years (Table 3.12). 56% and 63% of respondents in urban and sub-urban areas, respectively, were female ($p = 0.265$). 99.7% of all respondents were Buddhists, and

65% of them were married. 1.5% and 5% of respondents were uneducated in the urban and suburban areas, respectively. The urban respondents tended to have had their highest education at secondary, vocational and university levels as well as primary level, whereas 59% of the suburban respondents had their highest education only at the primary level ($p <$ 0.0001) (Table 3.13 and Figure 3.5). 89% and 69% of the suburban and urban respondents, respectively, were born in Chiang Mai ($p < 0.0001$). 3.3% of all respondents replied that they were suffering from respiratory diseases. In the suburban area, 3% of the respondents had respiratory diseases and 33% were suffering from other diseases including high blood pressure, paresis, and gastric ulcer. In the urban areas, 3.5% of respondents were suffering from respiratory diseases – asthma, allergy, sinus and tuberculosis.

Table 3.12 Descriptive statistics

Variable	N	Minimum	Maximum	Mean	Median	Mode
Age (years)	300	15	89	45.3	43	40
Years of living in Chiang Mai	300	1	89	37.6	38	20
Years of living in present address	300	1	89	30.2	25	2

Table 3.13 Summary of personal information collected by the questionnaire study

Part 1	Suburban		Urban		Total		p^a
Personal information	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	
Sex							**0.265**
Male	37	37.0	88	44.0	125	41.7	
Female	63	63.0	112	56.0	175	58.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*200.0*	*100.0*	
Highest education level							**<0.0001***
Primary	59	59.0	58	29.1	117	39.1	
Secondary	19	19.0	49	24.6	68	22.7	
Vocational	6	6.0	34	17.1	40	13.4	
University	11	11.0	55	27.6	66	22.1	
Uneducated	5	5.0	3	1.5	8	2.7	
Total (n)	*100*	*100.0*	*199*	*99.9*	*299*	*100.0*	
Religion							**1.000**
Buddhist	100	100.0	199	99.5	299	99.7	
Christian	0	0.0	1	0.5	1	0.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Marital status							**0.019***
Single	14	14.0	47	23.5	61	20.3	
Married	64	64.0	131	65.5	195	65.0	
Widow	19	19.0	16	8.0	35	11.7	
Divorced	3	3.0	6	3.0	9	3.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Birth place							**<0.0001***
Chiang Mai	89	89.0	137	68.8	226	75.6	
Other provinces	11	11.0	62	31.2	73	24.4	
Total (n)	*100*	*100.0*	*199*	*100.0*	*299*	*100.0*	
Illnesses							**0.001***
None	64	64.0	163	81.9	227	75.9	
Respiratory diseases	3	3.0	7	3.5	10	3.4	
Other illnesses	33	33.0	29	14.6	62	20.7	
Total (n)	*100*	*100.0*	*199*	*100.0*	*299*	*100.0*	

Note: [a] p-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

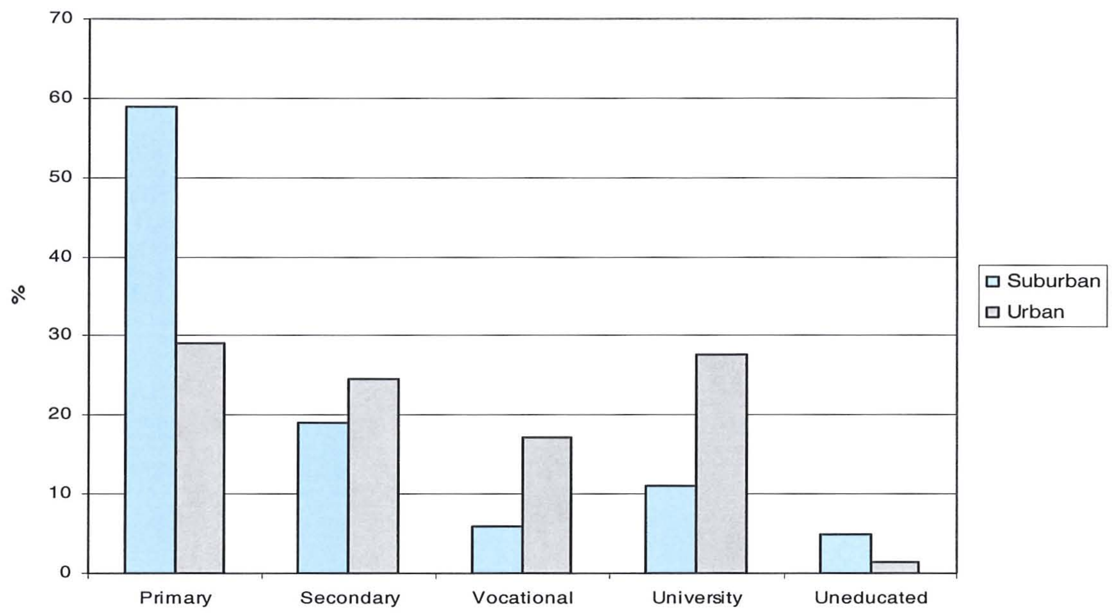


Figure 3.5 Highest level of education (percentage of respondents), *n* suburban respondents = 100 and *n* urban respondents = 199).

3.4.2 Part 2 – Lifestyle

Sixty-four percent of all respondents exercised regularly and 99.7% considered that their diets were healthy (Table 3.14). In the urban areas, 35% did not eat fruit and vegetables every day, 1.5% drank alcohol every day and 52.5% of the urban respondents drank occasionally. In the suburban areas, 98% ate fruit and vegetables every day, which is significantly different from the urban respondents, and only 19% drank alcohol occasionally. There was a significant difference in the number of alcohol drinkers between the two areas. 18% of suburban respondents were smokers whereas only 4% of the urban respondents smoked. Approximately, 80% of all respondents never smoked. For 26 smokers, the average number of cigarettes smoked per day was 4.7 and the average smoking duration was 25 years (Table 3.15). Nineteen percent of all respondents replied that their family members smoked. In the urban areas, the rate of colleagues smoking at work was 29% and this was higher than found for the suburban area (9%). Ninety-five percent of the suburban respondents replied that they were always happy, 5% of them replied that they were happy sometimes, and 63% of them never felt stressed. In contrast, 42% of the urban respondents thought that they were always happy, 84% of them reported stress occasionally, and 1.5% of them were continuously stressed. The causes of stress listed in the questionnaire were economic, health, work, study, family/relationship, and environmental problems.

Table 3.14 Summary of lifestyle information

Part 2 Lifestyle	Suburban Freq.	Suburban %	Urban Freq.	Urban %	Total Freq.	Total %	p^a
Exercise							**0.447**
No	39	39.0	69	34.5	108	36.0	
Yes	61	61.0	131	65.5	192	64.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Healthy diet							**1.000**
No	0	0.0	1	0.5	1	0.3	
Yes	100	100.0	199	99.5	299	99.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Alcohol drinking							**<0.0001***
Never	81	81.0	92	46.0	173	57.7	
Sometimes	19	19.0	105	52.5	124	41.3	
Everyday	0	0.0	3	1.5	3	1.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Fruit and vegetables							**<0.0001***
Occasional	2	2.0	70	35.0	72	24.0	
Everyday	98	98.0	130	65.0	228	76.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Cigarette smoking							**<0.0001***
Never	80	80.0	159	79.5	239	79.7	
Ever smoked but quitted	2	2.0	33	16.5	35	11.7	
Smoking	18	18.0	8	4.0	26	8.6	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Smoking of family members							**0.089**
No	75	75.0	167	83.5	242	80.7	
Yes	25	25.0	33	16.5	58	19.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Smoking of colleagues at work							**<0.0001***
No	91	91.0	142	71.0	233	77.7	
Yes	9	9.0	58	29.0	67	22.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Happy							**<0.0001***
Never	0	0.0	2	1.0	2	0.7	
Sometimes	5	5.0	114	57.0	119	39.7	
Always	95	95.0	84	42.0	179	59.6	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Stress							**<0.0001***
Never	63	63.0	29	14.5	92	30.7	
Sometimes	37	37.0	168	84.0	205	68.3	
Always	0	0.0	3	1.5	3	1.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Cause of stress/problem							**<0.0001***
Economic	9	25.0	11	6.5	20	9.8	
Health	3	8.3	0	0.0	3	1.5	
Work	4	11.1	3	1.8	7	3.4	
Study	2	5.6	3	1.8	5	2.5	
Family/relationship	12	33.3	4	2.4	16	7.8	
Environment	1	2.8	1	0.6	2	1.0	
Combination of above problems	5	13.9	146	86.9	151	74.0	
Total (n)	*36*	*100.0*	*168*	*100.0*	204	*100.0*	

Note: [a] p-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

Approximately, 87% of the urban respondents replied that more than one of these problems caused stress to them. In the suburban area, 33.3% and 25% considered that family/relationship and economic (low income) problems were main causes of stress. Only 1% of all respondents replied that their stress was caused by environmental problems.

Table 3.15 Descriptive statistics

Variable	N	Minimum	Maximum	Mean	Median	Mode
No. of cigarettes smoked per day	26	1	15	4.7	3.5	2
Smoking duration (years)	26	2	62	25.0	23.5	30

3.4.2.1 Factors affecting health

Factors affecting health listed in the questionnaire included: accidents; air pollution; noise; food; housing conditions; smoke; stress; lack of exercise; crime; and poverty (Table 3.16 and Figure 3.6). Approximately 80%, or more, of respondents in the suburban area did not consider that accidents, air pollution, noise, food, housing, smoke, lack of exercise, and crime affected their health. Forty-five percent and 36% of them replied that stress and poverty influenced their health. The urban respondents had different opinions about the factors that affect their health. Approximately 70% of them replied that stress and air pollution were main factors. Other factors reported were lack of exercise (45.5%), noise (39%), smoking (33.5%), poverty (31.5%) and housing (28%). There is a significant difference between the two areas for all of the above factors – with the exception of poverty and crime ($p < 0.05$).

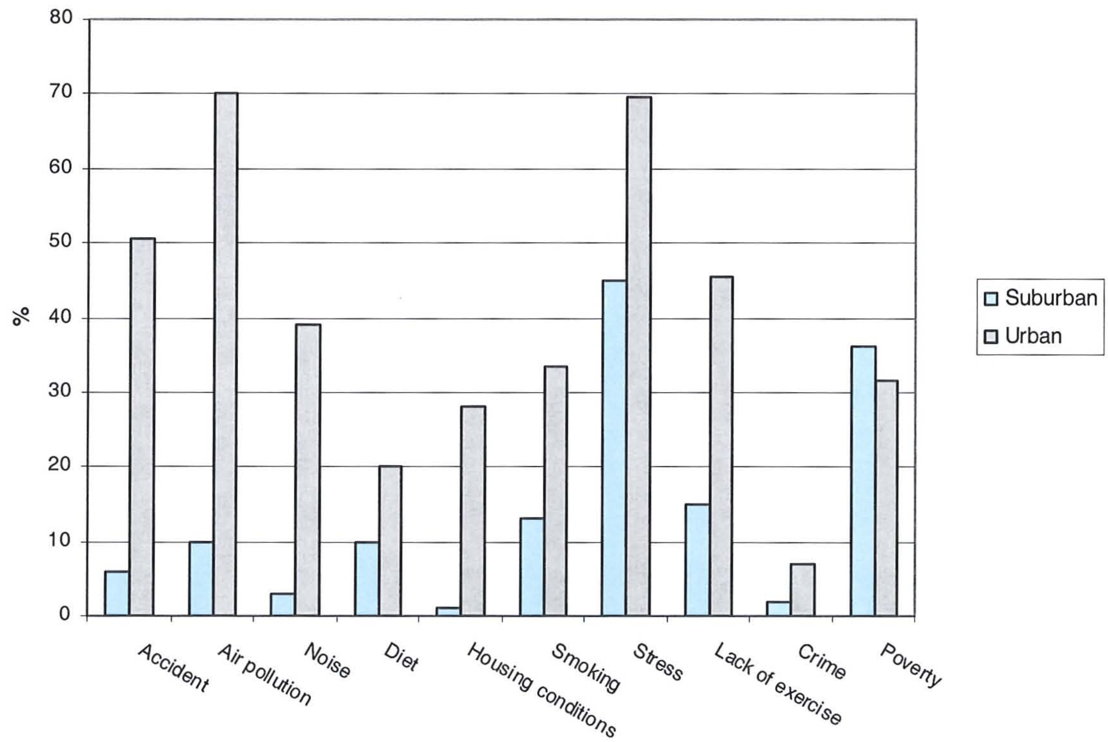


Figure 3.6 Factors affecting health as reported by respondents of the questionnaire study (n suburban respondents = 100 and n urban respondents = 200).

Table 3.16 Summary of factors affecting health

Factors affecting health	Suburban		Urban		Total		p^a
	Freq.	%	Freq.	%	Freq.	%	
Accident							**<0.0001***
No	94	94.0	99	49.5	193	64.3	
Yes	6	6.0	101	50.5	107	35.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Air pollution							**<0.0001***
No	90	90.0	60	30.0	150	50.0	
Yes	10	10.0	140	70.0	150	50.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Noise							**<0.0001***
No	97	97.0	122	61.0	219	73.0	
Yes	3	3.0	78	39.0	81	27.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Diet							**0.032***
No	90	90.0	160	80.0	250	83.3	
Yes	10	10.0	40	20.0	50	16.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Housing conditions							**<0.0001***
No	99	99.0	144	72.0	243	81.0	
Yes	1	1.0	56	28.0	57	19.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Smoking							**<0.0001***
No	87	87.0	133	66.5	220	73.3	
Yes	13	13.0	67	33.5	80	26.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Stress							**<0.0001***
No	55	55.0	61	30.5	116	38.7	
Yes	45	45.0	139	69.5	184	61.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Lack of exercise							**<0.0001***
No	85	85.0	109	54.5	194	64.7	
Yes	15	15.0	91	45.5	106	35.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Crime							**0.100**
No	98	98.0	186	93.0	284	94.7	
Yes	2	2.0	14	7.0	16	5.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Poverty							**0.438**
No	64	64.0	137	68.5	201	67.0	
Yes	36	36.0	63	31.5	99	33.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	

Note: ^{a} p-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

3.4.2.2 Illnesses in the past 12 months

The illnesses listed in the questionnaires included: asthma; eye irritation/dry eyes; migraine; lower respiratory infection, LRI (e.g. emphysema, lung infection, pneumonia); upper respiratory infection, URI (e.g. cold, influenza); and allergies (e.g. eczema, dust allergy). The illnesses which interviewees had had in the previous 12 months are illustrated in Table 3.17 and Figure 3.7. The urban respondents had a higher percentage of the above illnesses than the respondents in the suburban area. In particular, there were significant differences with respect to the responses for eye irritation, URI, and allergies between the respondents in the urban and suburban areas.

Table 3.17 Summary of illnesses experienced in the past 12 months

Illnesses in the past 12 months	Suburban		Urban		Total		p^a
	Freq.	%	Freq.	%	Freq.	%	
Asthma							**0.351**
No	95	95.0	183	91.5	278	92.7	
Yes	5	5.0	17	8.5	22	7.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Eye irritation/dry eyes							**<0.0001***
No	90	90.0	130	65.0	220	73.3	
Yes	10	10.0	70	35.0	80	26.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Migraine							**0.223**
No	82	82.0	175	87.5	257	85.7	
Yes	18	18.0	25	12.5	43	14.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Lower respiratory infection (LRI)							**0.554**
No	100	100.0	198	99.0	298	99.3	
Yes	0	0.0	2	1.0	2	0.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Upper respiratory infection (URI)							**<0.0001***
No	67	67.0	77	38.5	144	48.0	
Yes	33	33.0	123	61.5	156	52.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Eczema and other allergies							**<0.0001***
No	92	92.0	94	47.0	186	62.0	
Yes	8	8.0	106	53.0	114	38.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	

Note: [a] p-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

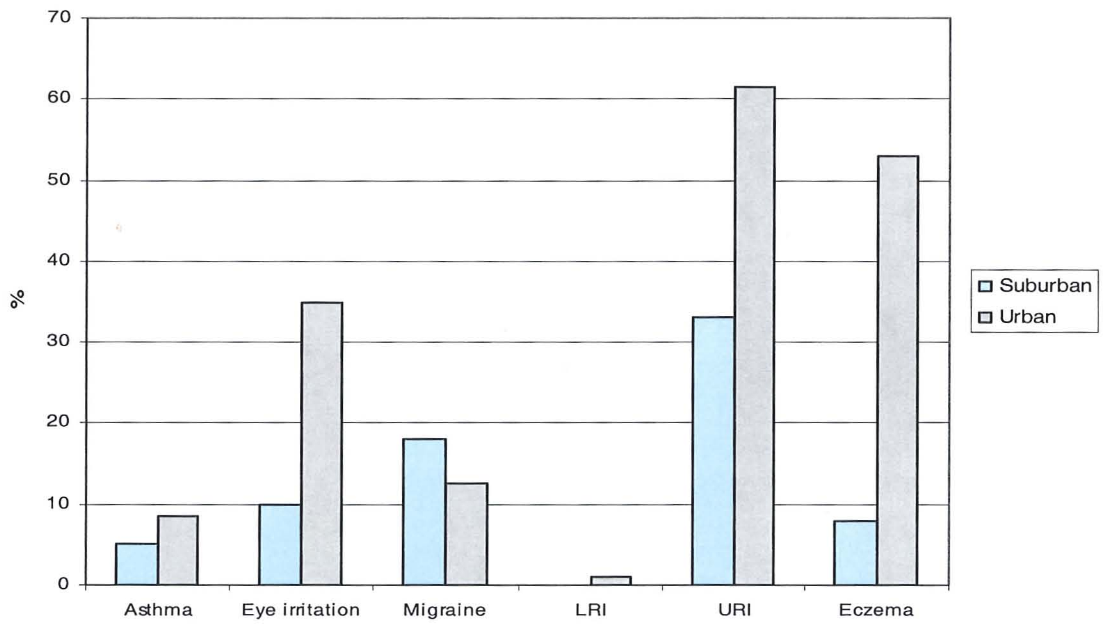


Figure 3.7 Illnesses experienced in the past 12 months (percentage of respondents) (n suburban respondents = 100 and n urban respondents = 200).

3.4.2.3 Means of transport

The results showed that most respondents in both urban and suburban areas travelled in Chiang Mai using their own vehicles, which were motorcycles and cars/trucks (Table 3.18 and Figure 3.8). Approximately 80% of the urban respondents used their own vehicles, 15% of them used taxis ('silor dang'/'songtaew', modified pick-up trucks) and/or 'tuk-tuk' (small three-wheeled motor vehicles)) and only 1.5% rode bicycles. In the suburban area, 68% used cars/trucks and motorcycles, and 21% of them used taxis.

Table 3.18 Summary of means of transport

Means of transport	Suburban		Urban		Total		p^a
	Freq.	%	Freq.	%	Freq.	%	
							0.004*
Never travelled	11	11.0	4	2.0	15	5.0	
By foot	0	0.0	1	0.5	1	0.3	
Bicycle	0	0.0	3	1.5	3	1.0	
Motorcycle	28	28.0	81	40.5	109	36.3	
Car/truck	40	40.0	80	40.0	120	40.0	
Taxi[b]	21	21.0	31	15.5	52	17.4	
Total	*100*	*100.0*	*200*	*100.0*	*300*	*100*	

Note: [a] *p*-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). [b] 'silor dang' ('songtaew') and/or 'tuk tuk'. *Significant.

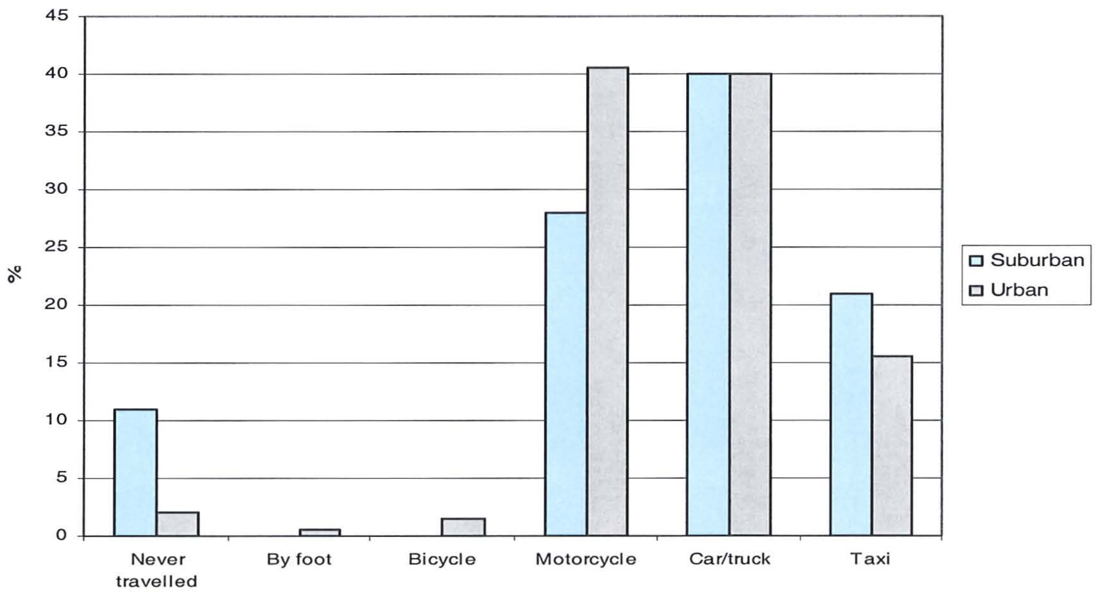


Figure 3.8 Means of transport (percentage of respondents) (n suburban respondents = 100 and n urban respondents = 200).

3.4.3 Part 3 – Housing Conditions

In the suburban area, 98% of the respondents lived in their own house, but only 61.5% of urban respondents lived in their house and 35.5% of them lived in rented accommodation (Table 3.19). Indoor factors, which may affect people's health, are summarized in Table 3.20 and illustrated in Figure 3.9. There were significant differences between the urban and suburban populations with respect to damp, lack of air conditioner/air filter, lack of air ventilation and dust in the house. Approximately 90% of the urban respondent replied that house dust was a main factor affecting their health. In the suburban area, 87% of the samples replied that there were no sources of air pollution in their area. In the urban areas, 60% and 22.5% of the respondents replied that the main sources of air pollution in their area were, respectively, traffic and domestic waste burning. All suburban respondents replied that there was no traffic congestion in their home area, whereas approximately 37% of the urban respondents replied that the traffic congestion was high in the rush hours, and 26.5% of them replied that traffic congestion was not too high or too low (medium). 97% of interviewees in the suburban area replied that the air pollution level in their area was low, while 57.5% and 13% of the respondents in the 'hot-spots' replied that the levels of air pollution in their area were medium and high, respectively (Table 3.19).

Table 3.19 Summary of housing conditions

Part 3	Suburban		Urban		Total		p^a
Housing conditions	Freq.	%	Freq.	%	Freq.	%	
Type of accommodation							**<0.0001***
Rented accommodation	1	1.0	71	35.5	72	24.0	
Own accommodation	98	98.0	123	61.5	221	73.7	
Others	1	1.0	6	3.0	7	2.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Traffic congestion							**<0.0001***
No traffic	100	100.0	57	28.5	157	52.4	
Low	0	0.0	13	6.5	13	4.3	
Medium	0	0.0	53	26.5	53	17.7	
High during rush hours	0	0.0	73	36.5	73	24.3	
Normally high	0	0.0	4	2.0	4	1.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Level of air pollution							**<0.0001***
Low	97	97.0	59	29.5	156	52.0	
Medium	2	2.0	115	57.5	117	39.0	
High	1	1.0	26	13.0	27	9.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Source of air pollution							**<0.0001***
None	87	87.0	19	9.5	106	35.4	
Traffic	1	1.0	120	60.0	121	40.3	
Factory	3	3.0	7	3.5	10	3.3	
Domestic waste burning	6	6.0	45	22.5	51	17.0	
Incinerator/crematorium	0	0.0	3	1.5	3	1.0	
Others	3	3.0	6	3.0	9	3.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	

Note: [a] p-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

Table 3.20 Summary of indoor factors affecting health

Indoor factors affecting health	Suburban		Urban		Total		p^a
	Freq.	%	Freq.	%	Freq.	%	
Damp							**<0.0001***
No	96	96.0	111	55.5	207	69.0	
Yes	4	4.0	89	44.5	93	31.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Lack of air conditioner/air filter							**0.002***
No	89	89.0	146	73.0	235	78.3	
Yes	11	11.0	54	27.0	65	21.7	
Total (n)	*100*	*100*	*200*	*100.0*	*300*	*100.0*	
Lack of air ventilation							**<0.0001***
No	88	88.0	51	25.5	139	46.3	
Yes	12	12.0	149	74.5	161	53.7	
Total (n)	*100*	*100*	*200*	*100.0*	*300*	*100.0*	
Dust							**<0.0001***
No	72	72.0	21	10.5	93	31.0	
Yes	28	28.0	179	89.5	207	69.0	
Total (n)	*100*	*100*	*200*	*100.0*	*300*	*100.0*	
Chemicals							**0.287**
No	74	74.0	135	67.5	209	69.7	
Yes	26	26.0	65	32.5	91	30.5	
Total (n)	*100*	*100*	*200*	*100.0*	*300*	*100.0*	
Cooking							**0.896**
No	69	69.0	135	67.5	204	68.0	
Yes	31	31.0	65	32.5	96	32.0	
Total (n)	*100*	*100*	*200*	*100.0*	*300*	*100.0*	

Note: [a] *p*-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

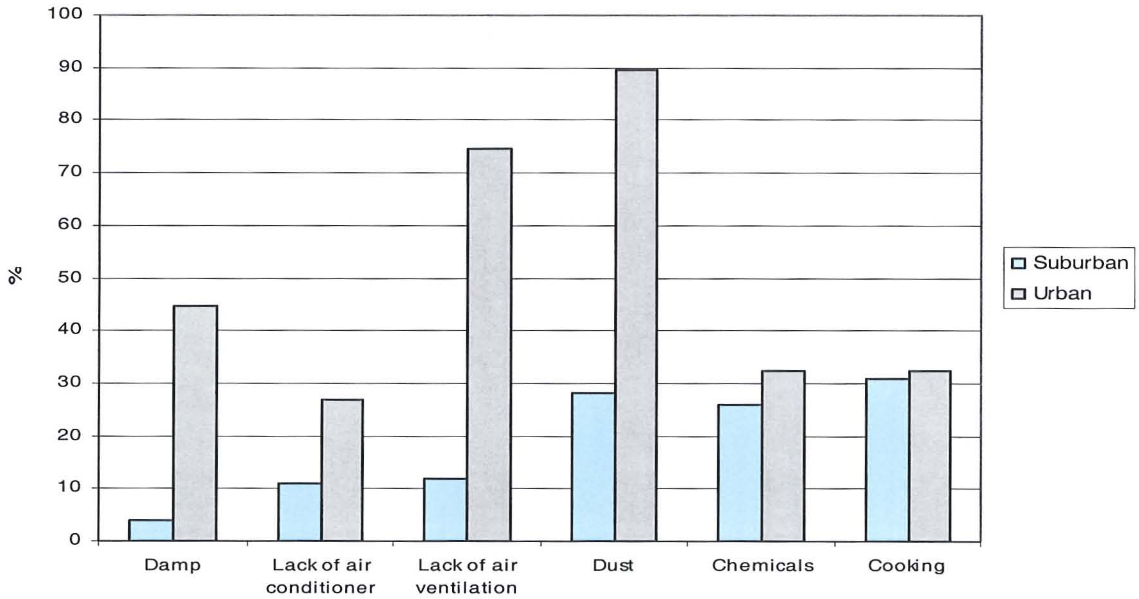


Figure 3.9 Indoor factors reported to affect health (percentage of respondents) (n suburban respondents = 100 and n urban respondents = 200).

3.4.4 Part 4 – Air Quality Information

The list of questions about air quality information in the questionnaire included: sources of air pollution; type of air pollutants; impact of air pollution on health; air pollution avoidance; air pollution mitigation; air quality forecast, air quality information at present; and air quality information in the past (Table 3.21). The results of the survey showed that most respondents in urban (88%) and suburban (86%) areas had never received air quality information (Table 3.22). However, approximately 78%-80 % of the suburban respondents and 58%-81% of the urban respondents were very interested in air quality information. The preferred media for the receipt of air quality information was television (62.7% of all respondents). Government publications were also chosen by 17% and 12.5% of urban and suburban respondents, respectively. Only 4% of all respondents wished to access air quality information through the internet.

Table 3.21 Summary of reported interest in issues concerning air quality information

Part 4 Air quality information	Suburban Freq.	Suburban %	Urban Freq.	Urban %	Total Freq.	Total %	p^a
Source of air pollution							**0.112**
No	3	3.0	9	4.5	12	4.0	
Interested but not much	18	18.0	56	28.0	74	24.7	
Very interested	79	79.0	135	67.5	214	71.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Type of air pollution							**0.051**
No	3	3.0	8	4.0	11	3.7	
Interested but not much	18	18.0	61	30.5	79	26.3	
Very interested	79	79.0	131	65.5	210	70.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Impact of air pollution							**0.662**
No	3	3.0	3	1.5	6	2.0	
Interested but not much	18	18.0	34	17.0	52	17.3	
Very interested	79	79.0	163	81.5	242	80.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Avoidance							**0.712**
No	3	3.0	3	1.5	6	2.0	
Interested but not much	18	18.0	36	18.0	54	18.0	
Very interested	79	79.0	161	80.5	240	80.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Mitigation							**0.537**
No	3	3.0	3	1.5	6	2.0	
Interested but not much	18	18.0	42	21.0	60	20.0	
Very interested	79	79.0	155	77.5	234	78.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Air quality forecast							**0.047**
No	3	3.0	4	2.0	7	2.3	
Interested but not much	18	18.0	61	30.5	79	26.3	
Very interested	79	79.0	135	67.5	214	71.3	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Present air quality							**0.114**
No	3	3.0	4	2.0	7	2.3	
Interested but not much	17	17.0	55	27.5	72	2.4	
Very interested	80	80.0	141	70.5	221	73.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Air quality in the past							**0.003***
No	3	3.0	15	7.5	18	6.0	
Interested but not much	19	19.0	69	34.5	88	29.3	
Very interested	78	78.0	116	58.0	194	64.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	

Note: [a] *p*-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

Table 3.22 Summary of air quality information of interest

Part 4 Air quality information	Suburban Freq.	Suburban %	Urban Freq.	Urban %	Total Freq.	Total %	p^{a}
Air quality information received							**0.713**
Never	86	86.0	176	88.0	262	87.3	
Yes but not often	14	14.0	24	12.0	38	12.7	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	
Preferred media of air quality information							**0.004****
Government publications	17	17.0	25	12.5	42	14.0	
National newspapers	2	2.0	19	9.5	21	7.0	
Local newspapers	0	0.0	4	2.0	4	1.3	
Internet	0	0.0	12	6.0	12	4.0	
TV	67	67.0	121	60.5	188	62.7	
Radio	10	10.0	11	5.5	21	7.0	
Others	4	4.0	8	4.0	12	4.0	
Total (n)	*100*	*100.0*	*200*	*100.0*	*300*	*100.0*	

Note: [a] *p*-value based on either Pearson χ^2 test or Fisher's exact test (the latter was used when counts in any of the cells were less than 5). *Significant.

3.5 Discussion

The Quality of Life (QoL) survey conducted in Chiang Mai used a questionnaire as a tool to evaluate residents' attitudes, covering the topics of gender (male/female), marital status, education, lifestyle, health, positive and negative feelings (happiness/stress), housing conditions (with respect to both indoor and outdoor air pollution) and level of interest in obtaining air quality information. Boynton and Greenhalgh (2004) suggested that a valid questionnaire should be able to measure what it claims to measure. Generally speaking, if the designed questionnaire can answer the research questions contained within its objectives, the questionnaire is valid. The main objective of the Chiang Mai survey was to investigate attitudes of urban and suburban residents to air pollution and health. The questions are discussed as follows based upon the WHO Quality of Life domains (WHO, 1996) (referred to hereafter as WHOQOL). However, it should be noted that to evaluate the scoring of QoL for the Chiang Mai survey following the WHOQOL rating was not possible because of the difference in questionnaire design. WHO (1996) used a 5 point scale method (Likert scale) in the questionnaire (e.g. very dissatisfied, dissatisfied, neither satisfied nor dissatisfied, satisfied, very satisfied), whereas, a nominal measure was mainly used in the Chiang Mai questionnaire. A nominal measure produces qualitative or categorical data that provide no information about quantity. Therefore, only the frequency (and percentages) of each item (e.g. urban respondent vs. suburban respondents) could be summarised.

The questions in Section I were grouped as general questions about respondents (Table 3.9), similar to the first section of the WHOQOL questionnaire (WHO, 1996). These are standard classification questions (e.g. age, gender, education, marital status) (Jarrett, 2004). The questions are straightforward. However, a question about occupation should have been included in this section. The author did not agree with the exclusion of the question regarding occupation of respondents because different occupational activities can have significantly different impacts on health. For example, construction workers, who are generally exposed to outdoor air pollution (especially particulate matter), may have respiratory and/or pulmonary function impairment more frequently than bankers, who work in clean air-conditioned offices. This may correspond to different QoL among different occupations. Jean *et al.* (2006) found that chronic bronchitis symptoms and airflow obstruction were associated with occupational exposure in a population in the textile industry. Additionally, lung impairment was related to the duration of occupational exposure, being independent of the effect of smoking.

Questions about illnesses or physical impairment, religion, marital status and health insurance scheme are QoL facets incorporated within all four domains - physical health, psychological, social relationships and environment domains respectively (Section 3.1.1). The results from Section I of the questionnaire showed a higher percentage of female respondents in both urban and suburban areas. Urban respondents had achieved significantly higher levels of education than suburban respondents, especially at vocational and university levels. In the past, children from poor socio-economic backgrounds, such as farming families, were sent only to primary schools because primary education was compulsory in Thailand and they were not able to support their children through higher education (pers. comm. Ms. Jaree Jaimook). Respectively, 1.5% and 5% of suburban and urban residents were uneducated which may imply that they were illiterate. The personal interview is an efficient means of gathering information that overcomes the obvious problems of accessing people with minimal levels of literacy. Due to Buddhism being the national religion of Thailand, it is not surprising that all but one of the respondents were Buddhists. The results from the marital status question indicate that most of the respondents (approximately 64-66%) in both areas were married. A higher percentage of urban respondents were single (23.5% vs. 14% for suburban area). However, it cannot be inferred that they were not in personal relationships. A more accurate indication of personal relationships may have been gained if the answers to this question included "partner/girlfriend/boyfriend". The question regarding birthplace in the questionnaire may not have had the same relevance as the question concerning ethnicity in the LBB version, because in Thailand there is little ethnic diversity.

The questions in Section II also cover all WHOQOL domains. The questions were straightforward but the wording 'sometimes' may not be the best to use for questions such as "how often do you drink alcohol?". Boynton and Greenhaplgh (2004) recommended that frequency options such as "at least once a day" or "twice a week" may be more appropriate. The results showed that urban respondents reported more respiratory diseases (excluding asthma), eye irritation/dry eyes, upper respiratory infections, and allergies including eczema than the suburban respondents. The results are consistent with air pollution affecting the health of urban respondents. However, it cannot be concluded that the urban respondents were more health-aware than suburban respondents. For example, 16.5% of urban respondents had stopped smoking and only 4% of them were smokers. 29% of colleagues of urban respondents smoked at work which was significantly higher than for respondents living in the suburban area (9%). The banning of cigarette smoking in public places has been introduced to Thailand since 2002 (White, 2003), but it has not yet been stringently enforced in Chiang Mai, particularly in restaurants. Stress and air pollution were the main factors claimed by urban respondents to be affecting their health, while stress and poverty were predominantly the main factors claimed in this regard by suburban respondents. Air pollution was not generally felt to be a priority problem in the suburban area, while it was a cause for concern among urban respondents. Between the urban and suburban areas, the differences are strongly significant ($p < 0.0001$), for damp, lack of air ventilation and house dust, which are likely to be indoor factors affecting health. In addition, among urban respondents who experienced stress, they were more likely to identify combined causes, whereas suburban respondents were more likely to report single causes such as family and relationship (33.3%) and economic (25%) problems.

Sections III and IV of the questionnaire focused mainly on the environment facets of WHOQOL Domain IV (Section 3.1.1) which include home environment, physical environment (including air pollution) and opportunities for acquiring new information. The Section III results showed that more respondents in the urban areas accepted that they were exposed to medium to high levels of air pollution, than respondents in the suburban area. This is consistent with measured values and it would seem that, where there is a lack of air quality data, public perception could be a reasonable indicator to validate the results of air quality modelling in Chiang Mai (Chapter 2). In addition, the respondents generally considered that traffic and the burning of domestic wastes polluted the air. Over 60%

replied that there is traffic congestion in their areas. It was surprising that most people in both urban and suburban areas claim to have never received any air quality information. This may imply that there is no distribution of air quality information or the distribution by responsible local organisations in Chiang Mai (e.g., the Environmental Office, Chiang Mai Municipality, and Provincial Administration Office) is ineffective. There has recently been another project concerning air quality conducted in Chiang Mai; *Building Capacity of Thai Federal and a Provincial Air Quality Department* (2002), by the Pollution Control Department (PCD) and Chiang Mai Municipality (CMM), which educated their officers in air pollution management. However, such measures may not be sufficient and local organisations should also consider employing air quality experts to assist in local air quality management (LAQM). LAQM should be prioritised in environmental management policy in Chiang Mai. Approximately 66% of all respondents preferred television to be the principal medium for the distribution of air quality information and responsible organisations could initially use a local daily TV news programme to broadcast daily air quality information and forecasts as part of the weather forecast. Radio and publications such as booklets or leaflets should also be considered as suitable media for disseminating air quality information.

The modified Thai version of the questionnaire contained questions that were easy to comprehend because of the use of simple language both in the questionnaire and the personal interview. The use of technical and ambiguous words was avoided. However, the respondents who did not understand some questions could also ask the interviewers for an explanation (all interviewers were carefully briefed on each question in the questionnaire before the field survey). Questionnaire distribution was particularly efficient in the Chiang Mai survey where interviewers had to select respondents according to 3 criteria (i.e. ≥15 years of age, address and ≥1-year stay at the given address). The door-to-door approach using university students appeared to receive substantial co-operation and it was the author's experience that Chiang Mai people were generally friendly and co-operative towards students. When respondents were too busy to be interviewed (e.g. business/shop owners), they normally asked if they could complete the questionnaire by themselves (self-administered) while the interviewers waited to answer any enquiries and to collect the completed questionnaires. During the survey, it was found that some respondents did not appreciate being asked about their highest level of education. Also, if there was a couple in the house, the wife was often asked by the husband to complete the interview. Generally, females appeared to be more cooperative with the interviewers than males (pers. comm. Ms. Viranlapach Sunhinnapongse).

In this study, there are some uncertainties arising from potential biases in some processes as follows;

- ***Sampling method*** – A judgment or purposive sampling approach was applied in this study, which is a non-probability sampling method. The sample would therefore probably not be a representative subset of the population, as in random sampling methods. Statistically, this kind of sampling method causes selection bias that can distort an analysis of data. In general, sample selection may involve pre- or post-selection which may preferentially include or exclude certain kinds of results (Wikipedia, 2006). In this study, the urban respondents who were selected lived in areas near the junctions of major roads where traffic was obviously busy. Not surprisingly, most of them (70%) believed that air pollution was a major factor affecting their health and 60% of them considered that traffic was a main source of air pollution. These percentages may have been lower if the respondents were selected by random sampling methods (see Table 3.6) in general urban areas with a range of traffic conditions. Hence, the results of this questionnaire survey are not generalisable for urban areas. Rather, they focus upon urban respondents residing in pollution 'hot-spot' areas particularly those living near busy roads or in commercial areas (and only the results for urban respondents in Muang and Saraphi Districts were summarized in this chapter). However, the sample was intentionally selected (purposive sampling) as part of the MAQHUE project. The cost of conducting the survey using random sampling methods would be higher due to greater administrative requirements (e.g. field work in larger study areas, larger sample numbers, more trained interviewers required, etc.).

- ***Administration of questionnaires*** – Uncertainties may have occurred in cases where the respondents completed the questionnaire by themselves. If the interviewers were in a hurry and did not thoroughly check that all the questions were completed, some data would be lost. For instance, one urban respondent did not answer the question about educational level in this questionnaire survey. In addition, under time pressure, interviewers may tick the wrong box. Interviewers can also subtly influence responses by inflections of the voice, facial expressions or gestures (Boynton *et al.*, 2004). For example, they may unconsciously hurry through questions they wrongly perceive as unimportant or uncomfortable. Or their tired or unenthusiastic facial expression may cause respondents to hesitate to ask about questions that they may not understand. Boynton *et al.* (2004) recommended that, to avoid these problems, it would be better for interviewer performance if they are paid by the hours they work, rather than per questionnaire completed as in the Chiang Mai study.

- ***Respondents' biases*** – The suitability of a questionnaire, such as that employed for this study, to assess air pollution exposure and health status may be questioned because generally people may not be able to recall past events (e.g. asking about their illnesses in the past 12 months) (Jarrett, 2004). In addition, the urban respondents, where a higher prevalence of respiratory and allergic diseases was reported (Table 3.17), also generally claimed that air pollution was one of the main factors that affected their health (Table 3.16). This may be because urban respondents had interpreted that air pollution in their areas impacted upon their health, rather than unhealthy facets of their lifestyles (e.g. lack of exercise, cigarette smoking). Hunter *et al.* (2004) conducted a cross-sectional survey using a questionnaire to investigate English perceptions of air pollution. It was found that respondents from homes with a person reporting respiratory symptoms were more likely to report odour pollution than from homes with no person showing respiratory symptoms. This is recall bias arising from two possible reasons: (i) air pollution may exacerbate their symptoms; therefore affected residents were more aware of poor air quality because they were more symptomatic where air pollution was worse; (ii) people with respiratory diseases believe that their illnesses were caused by air pollution so they may over report the level of exposure. Moreover, in the Chiang Mai study, some respondents may not have been concerned about air pollution before the interviewers introduced the objectives of the survey and they may subsequently have thought that it was appropriate to select answers relating to air pollution. This may be a type of response bias in the survey where respondents intentionally respond to please the interviewers. Lack of privacy, occurring when friends or relatives interjected, or even they were only listening during the interview, can also cause a response bias (Boynton *et al.*, 2004). For example, they may reply that they were non-smokers although they secretly smoked, or, in the presence of their friends or family members alcoholics may reply that they only drank alcohol sometimes.

Although the questionnaire to investigate people's perceptions of air pollution and health may have had some limitations as mentioned above, Oglesby *et al.* (2000) were convinced that the population mean perception is a good indicator of exposure to air pollution – especially for measuring long-term pollution severity. Indeed, studies of the health impacts of air pollution that concentrate only on chemical exposure will be flawed unless perception and socio-behavioral factors are addressed (Hunter *et al.*, 2004).

- ***Validity*** – Questionnaire validation, which should have been part of the piloting process, was not conducted in the study in Chiang Mai. There are many validity testing methods but 'content validity' could be conducted to test how well the items (questions) in the questionnaire measure what they intend to measure. Carr-Hill and Chalmers-Dixon (2002) summarized requirements for content validity for a health status questionnaire as follows: the main topic headings should be appropriate to the overall aims of the measurement; the chosen items should relate to the definition and aim of their headings; and the wording should be intelligible to respondents and unlikely either to be misunderstood or to cause offence. A test for content validity should involve piloting the questionnaire with representative respondents in order to obtain feedback on acceptability and intelligibility, which help to improve questionnaire reliability. In addition, statistical techniques for content validity testing (e.g. multi-trait scaling and factor analysis) can be applied in order to eliminate items that are least related to the study aims (Carr-Hill and Chalmers-Dixon, 2002). In this study, the validity of the questionnaire cannot be analysed because validity testing and piloting were not considered as part of the questionnaire survey project in Chiang Mai. Inclusion or exclusion of items in the questionnaire was based on judgment (e.g. appropriate to Thai culture) rather than a validity test. If the questionnaire used in the survey had been through the complete pilot survey, including validity testing, before final confirmation of questionnaire content, it may have consisted of items better-related to the objectives of the survey. For example, some useful items regarding occupational description may not have been removed from the questionnaire.

3.6 Conclusion

The health survey was conducted in 2 urban areas (Saraphi and Poi Luang Junctions) and 1 suburban area (San Pooleui, Doi Saket District) in Chiang Mai, Thailand using a questionnaire. The results show that respondents in air pollution 'hot-spot' areas had a higher percentage of respiratory diseases in the previous 12 months than the respondents in the suburban area. The main factors found to potentially affect people's health in the urban areas were air pollution and house dust. The main sources of urban air pollution were traffic and rubbish burning. In addition, most of the respondents in both urban and suburban areas use their own cars and motorcycles for travelling within Chiang Mai. Furthermore, most of the respondents in both areas had never received air quality information. Nevertheless, they were generally interested in obtaining this information and television was selected by most respondents to be the preferred medium for air quality information dissemination. The results of this study will be used to help formulate recommendations for sustainable measures that could be implemented for Local Air Quality Management (LAQM) in Chiang Mai.

CHAPTER 4

THE PREVALENCE OF RESPIRATORY DISEASES AND ALLERGIES AMONG SCHOOL CHILDREN IN CHIANG MAI

4.1 Introduction

From the results of air quality modelling in Chiang Mai, conducted during August – September 2003, schools in designated highly polluted and relatively non-polluted areas were identified and selected to be study areas for the third research component. The main objectives of this component – a study of respiratory diseases and allergies among school children in Chiang Mai – were: to investigate the respiratory health of children in selected primary schools that are located near to busy roads in Chiang Mai; to compare the prevalence of allergies, eczema and respiratory symptoms in children attending 6 primary schools (4 located in urban areas and 2 in a suburban area) which were designated ADMS-Urban receptor points (see Table 2.10).

The author and supervisory teams both at Middlesex University (MU) and Chiang Mai University (CMM) were aware that, as this research would be conducted on children, involving a parent-administered questionnaire, interviews of both parents and children, lung function measurements and weight and height measurements, it was crucial to obtain formal approval from the MU Ethics Committee (Appendix 1). Such ethical approval was not required in Chiang Mai, but official letters requesting permission (in Thai) to conduct the study were issued (with a copy of the ISAAC questionnaire attached) by Dr. Phongtape Wiwatanadate, Department of Community Medicine, CMU (acting as Co-supervisor of the PhD project), to the head teachers of six primary schools and all of the parents (n=620). Moreover, when the lung function measurements were conducted at each school, either Ms. Kitirat Mahasu or Ms. Siriboon Yavichai, Senior Nurses from Maharaj Nakorn Chiang Mai Hospital (CMU Hospital), supervised and assisted the author (approved by Associate Professor Supot Wudhikarn, M.D., Dean of Faculty of Medicine). Medication for asthmatic children was prepared and all equipment for lung function measurements was thoroughly cleansed by Ms. Mahasu. The measurements were also always attended by representative teachers at each school.

The ISAAC questionnaire survey and lung function study were designed with supervision from Associate Professor Muthita Trakultivakorn, Faculty of Medicine. She provided the author with the Thai version of the ISAAC questionnaire (Phase II), spirometer and peak flow meters for use in this study.

4.1.1 The International Study of Asthma and Allergies in Childhood

A standardised questionnaire produced for the International Study of Asthma and Allergies in Childhood (ISAAC) was applied in this study (see Appendix 8). ISAAC was initiated in 1991 in order to maximise the value of epidemiological research into asthma and allergic diseases, by establishing a standardized methodology and facilitating international collaboration (Asher *et al.*, 1995). The main concept of ISAAC was to develop a simple framework to compare the distribution of symptoms of asthma and allergies across the world (i.e. to standardize measurement practices and facilitate comparisons from one location to another, across geographic, cultural and linguistic boundaries). ISAAC's straightforward techniques can be undertaken at any location and with few financial resources, enabling truly global participation (Enarson, 2005). The standardized questionnaire was designed so that all participants are asked precisely the same questions in an identical format (Boynton and Greenhalgh, 2004).

The ISAAC protocol comprises three phases, administered over a set time period. Phase 1 uses a core questionnaire to assess the prevalence and severity of asthma and allergic diseases in different countries. Phase 2 investigates possible environmental factors that could be linked to the diseases and Phase 3 repeats Phase 1 to assess trends in prevalence at a later date. In this Chiang Mai study, the questionnaire included core questions about the prevalence of asthma, rhinitis and eczema; and supplementary questions on child contact modules (e.g. to pets and farm animals) as used in Phase 2 of the ISAAC protocol (Appendix 8). The Thai version of the ISAAC questionnaire covered demographic variables (age and home address); current and past symptoms of asthma, rhinitis and eczema; and various environmental factors. The questionnaire contained 5 parts. Part 1 requested information on school and student names, dates of birth, sex, race, home address and telephone number. Parts 2 – 4 related to specific health problems, namely, asthma, rhinitis and eczema. Part 5 covered environmental factors, including household experiences of traffic pollution, cigarette smoking by parents and by other family members, breast feeding history and pets. Lung function tests were also conducted on selected asthmatic and non-asthmatic school children. The fieldwork for this study was conducted at the start of the semester in November 2003.

It has been found, however, that the ISAAC questionnaire has some limitations. The original questionnaire was compiled in English and therefore it needed translation into different languages for application in non-English speaking countries. For example, linguistic problems were found in some countries such as Thailand and Ethiopia. A study was conducted to determine common Thai wordings actually used by Thai children and adolescents to describe wheeze, chest tightness, shortness of breath and dyspnea (Phankingthongkum *et al.*, 2002). The results of the study suggested that wheeze should be referred to (in Thai) as '/ha:də/' (a sound of deep breath) (not '/wi:d/', as it sounded similar to the English word 'wheeze', as normally used in Thai ISAAC survey). In addition, dyspnea was referred to as rapid breathing and feeling tired; and shortness of breath was more commonly referred to as 'not being able to catch a breath', 'too short a breath', 'not enough breath' and 'feeling suffocated'. Haileamlak *et al.* (2005) analysed the validity of the ISAAC questionnaire to investigate atopic eczema among Ethiopian children. It was found that the questionnaire did not perform especially well in identifying cases of atopic eczema in the survey due to problems with questionnaire translation, cultural conceptions of terminology and asking parents rather than the child about symptoms. It would seem that the ISAAC questionnaire has problems in both Thailand and Ethiopia and its use in non-western countries should be undertaken with caution. Local terms for asthma, rhinitis and eczema should be identified and validated in each language to obtain reliable epidemiological data. In Chiang Mai, it was found that some parents misunderstood what was meant by wheezing symptom, believing it to refer to snoring or heavy-breathing sounds. However, the true meaning was explained via telephone interview with some parents who reported wheezing of their children in the questionnaire.

4.1.2 Other Respiratory Health Related Questionnaires for Pediatric Research

The Pediatric Asthma Quality of Life Questionnaire (PAQLQ), developed by Juniper *et al.* (1996), has been used to measure the quality of life in children with asthma. PAQLQ was designed for administration to asthmatic patients aged between 7-17 years. It includes 23 items in three domains to assess symptoms, emotional function and activity limitations (e.g. playing with friends, riding a bicycle). This questionnaire was designed to be either self-administered or via personal interview, in the absence of parents. Poachanukoon *et al.*

(2005) validated the Thai (translated) version of PAQLQ in a cohort of asthmatic patients followed over five weeks. This process demonstrated correlations between various PAQLQ domains with clinical asthma parameters [e.g. peak expiratory flow rate (PEFR) and asthma symptoms], confirmed in both cross-sectional and longitudinal studies. It was concluded that the Thai version of PAQLQ is valid and reliable for implementing with Thai asthmatic children (Poachanukoon *et al.*, 2005). However, the Thai PAQLQ was not available when the author conducted the ISAAC questionnaire survey in Chiang Mai (2003-2004).

The Pediatric Rhino-conjunctivitis Quality of Life Questionnaire (PRQLQ) was similarly designed to measure quality of life in children, aged 6-12 years, with allergic rhino-conjunctivitis (or allergic rhinitis) (Juniper *et al.*, 1998). This instrument is a self-administered questionnaire that consists of 23 items regarding nose eye and other symptoms, practical problems and activity limitations. However, PRQLQ has not yet been translated into Thai for pediatric health-related research in Thailand.

Matza et al. (2004) recommended that it is important to consider length and number of measurements in a pediatric study because younger children in particular may provide inaccurate responses if the length of assessment exceeds their attention span or patience. In addition, children have a tendency to provide a certain response regardless of the question ('response set'). A common child response set is to provide extreme answers (e.g., response of only 1 or 5 on a series of 5-point Likert scales). This may be because they do not understand the questions but answer them in an attempt to appear competent. Response sets are problematic because they cause data to be biased, skewed or inaccurate. Therefore, assistance from parents is crucial when assessing younger children.

4.1.3 Lung Function Measurements

In this study, lung function measurements were conducted on some children with asthma (and age-matched healthy subjects as controls) in order to investigate the prevalence of exercise-induced asthma. Asthma is an obstructive lung disease due to inflammation of the airways, increased mucus production and contraction of the bronchial smooth muscles. Asthmatic patients generally produce an airway hyperreactivity response to some stimuli (i.e. exposure to aero-allergens such as dust and tobacco smoke) that make the airways narrower leading to recurrent spontaneous obstructive symptoms (Deshmukh, 2000). This results in low forced expiratory volumes and flow rates (see Sections 4.1.1.1-4.1.1.3). In addition to inhaled chemical mediators (e.g. histamine), asthma symptoms can also be triggered by natural physical stimuli (e.g. exercise, hyperventilation of cold air). Deshmukh (2000) estimated that approximately 70% of all asthmatic patients in the Western societies are exercise-induced. The main asthmatic symptoms and signs include coughing, wheezing, shortness of breath, chest tightness and prolonged expiration. The investigation of asthma is conducted by the use of several methods which include chest x-rays, sinus x-rays, bronchial challenge tests (e.g. with cold air), immune function studies and lung function tests. However, lung function tests should be conducted for preliminary investigations (Deshmukh, 2000).

Lung function measurements provide a direct assessment of airflow limitation. There are different methods to assess the level of airflow inhibition, but the measurement of forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), and peak expiratory flow (PEF) have been widely accepted for use to determine disease status in asthmatic patients over 5 years of age. FEV_1 and FVC are undertaken during a forced expiratory manoeuvre using a spirometer (GINA, 2002). FEV_1 is considered to be the best characterised test of respiratory function to assess asthma severity (Deshmukh, 2000; GINA, 2002). Information on changes in FEV_1 with age, gender, ethnic group, growth, and disease is more developed than for any other test. Normally a spirometer produces a printout of recorded FEV_1 and FVC results, with a volume-time graph. Spirometry recordings are useful in diagnosing asthma and assessing its severity. However, the validity of FEV_1, FVC and PEF depend upon the subject's effort and cooperation as well as on the instruction and coaching provided by administering personnel (Ms. Katirat Mahasu and Ms. Siriboon Yavichai). It was observed in the Chiang Mai study that a demonstration by the nurses assisted the children in giving a full effort.

The terms, forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1) and peak expiratory flow (PEF) are explained as follows;

4.1.3.1 Forced Vital Capacity (FVC)

The forced vital capacity (FVC) is the maximum volume of gas that can be expired by the subject as forcefully and rapidly as possible, after a maximal inspiration to lung capacity (Total Lung Capacity, TLC) (Ruppel, 1994). The FVC is measured by a flow-sensing spirometer (Figure 4.1). FVC may be reduced in patients with chronic or acute asthma, chronic bronchitis, bronchiectasis or cystic fibrosis (Ruppel, 1994). FVC values less than either 80% of the predicted value or the 95% confidence limit are interpreted as abnormal in terms of both obstructive and restrictive pulmonary diseases. However, it is also possible that a sub-normal FVC recording may be interpreted as simply insufficient breathing effort by the subject. Similarly, the common cold may reduce FVC performance in otherwise healthy subjects. Consequently, one needs to be careful when considering the results produced by an apparently healthy subject with no history of either persistent coughing or wheezing. For the study in Chiang Mai, the MicroLoop™ spirometer used requires input data of age, height, gender and ethnic group for calculation of the predicted FVC and FEV_1 values.

4.1.3.2 Forced Expiratory Volume in 1 Second (FEV_1)

The forced expiratory volume in one second (FEV_1) is the volume of gas expired over a one-second interval from the beginning of the FVC manoeuvre (Ruppel, 1994). If a subject begins the FVC manoeuvre slowly or with hesitation, the result of the FEV_1 may be inaccurate. The FEV_1 is the most widely used and best standardised index of obstructive diseases. A reduction in FEV_1 can be caused by airway obstruction resulting from mucus secretion, bronchospasm or inflammation in patients with asthma or bronchitis. FEV_1 measurements begin to be unreliable at values of less than 1 l/sec. In normal adults, the FEV_1/FVC ratio should be greater than 80%. The ratio may possibly be greater than 90% in children with normal lungs. Airflow limitation is suggested to reduce this ratio (GINA, 2002). A revised lower limit for the normal range (LLN) for adults of 70% was later recommended by Fabbri and Hurd (2003) (cited by Enright *et al.*, 2005). But using a fixed LLN to interpret spirometry results may lead to misclassification of diseases in case of falsely positive results (e.g. healthy persons being told that they have a disease) (Enright *et al.*, 2005). It was also suggested that LLN should be age and sex-specific rather than a fixed value. Particularly for children below 7 years, prediction of values should never be based upon those extrapolated from older subjects (Merkus *et al.*, 2005).

However, the use of spirometers to monitor asthma has some limitations in that they are expensive and difficult to use and maintain, and the reports sometimes are difficult to interpret (Enright *et al.*, 2005). The maneuver is highly dependent on patient cooperation and effort, and is normally repeated at least three times to ensure reproducibility (it takes longer than using a peak flow meter for PEF testing). If the subjects do not give full effort, the results can be under-estimated (Wikipedia, 2006). There are three phases of the required "unnatural" breathing manoeuvre as follows: i) maximal inhalation; ii) maximal exhalation for at least one second (for FEV_1); iii) continued exhalation for several seconds (for FVC). A sub-maximal exhalation during the second phase affects FEV_1, and incomplete (short) exhalation during the third phase reduces FVC results (Enright *et al.*, 2005). The most common cause of error is inadequate spirometry training and experience of the person administering the test. Inaccuracy or malfunction of the device is much less frequently at fault. In the study in Chiang Mai, administrator error was avoided by involving two senior nurses, experienced in lung function tests in children, who conducted the measurements. The spirometer was also calibrated monthly by Ms. Mahasu. The procedure employed in Maharaj Nakorn Chiang Mai Hospital which was used in this study was similar to international standards for lung function tests and spirometry according to the American Thoracic Society (ATS) and European Respiratory Society (ERS) (pers. comm., Dr. Muthita Trakultivakorn).

4.1.3.3 Peak Expiratory Flow (PEF)

Peak expiratory flow (PEF) is defined as 'the maximum flow achieved during an expiration delivered with maximum force starting from maximal lung inflation'. It has been used to characterise lung function in epidemiological studies (Pride, 2000). PEF is determined by the size of the lungs, lung elasticity, the dimensions and compliance of the central intra-thoracic airways, and the strength and speed of contraction of the expiratory (chiefly abdominal) muscles. Peak flow meters (see Figure 4.1) are useful in clinical and primary care for the diagnosis of asthma where more comprehensive spirometry is impractical (GINA, 2002). Regular monitoring of PEF at home, school or workplace, using a simple peak flow meter is useful because it can help patients to detect early signs of asthma deterioration. However, PEF measurements do not always correlate with other lung function measurements in asthma and are not interchangeable in evaluating asthma severity (GINA, 2002). In the diagnosis of asthma and assessment of its severity, PEF should be measured more frequently than twice daily. A diurnal variation in PEF of more than 20 percent is considered to be diagnostic of asthma.

4.2 Methodology

The methodology employed for the study of Respiratory Diseases and Allergies among School Children in Chiang Mai is as follows;

i) Six schools (ADMS-Urban receptor points) were visited in order to check if the required age group (6-12) was represented, and to deliver a letter to the head teacher asking for permission to conduct the study. The objectives of the study, the ISAAC health questionnaire (Appendix 5) and lung function tests were explained to each head teacher. Six hundred and twenty copies of the questionnaire were delivered to the six selected schools along with a letter to parents explaining the study objectives and asking their permission to conduct lung function tests on their children. The questionnaires were completed by the parents.

ii) The questionnaires were completed and returned within one week. Data coding was later conducted by hand for each questionnaire. In the case where either unclear or incomplete answers were provided (90 questionnaires), parents were interviewed, via telephone, and selected students were interviewed if their parents could not be reached by telephone. Twenty-five parents who provided telephone numbers were interviewed. The students (n=15) whose parents did not provide contact numbers were interviewed in the presence of teachers. Particular attention was given to the questions relating to the symptoms of asthma (wheezing), hay fever, and atopic dermatitis. These were always confirmed by interviewing the subjects whose parents gave positive answers in the questionnaire. This was necessary because some parents were not able to differentiate between: i) heavy breathing after exercise vs. wheezing, or snoring vs. wheezing; ii) cold vs. hay fever; iii) normal rash vs. rash at flexural areas (diagnosis of atopic dermatitis). Forty incomplete questionnaires were not included in the statistical analysis of data. The criteria for rejection included: i) the returned questionnaires were totally incomplete; ii) the questions regarding wheezing, rhinitis and eczema symptoms were incomplete; iii) the parents were illiterate or provided 'response set' answers (e.g. ticked the first box or the last box for all the questions). There was one case where the parents of a boy were Burmese immigrants and gave positive answers for questions about wheezing, whereas the child informed the author that he never experienced wheezing and his parents could not read Thai.

iii) A list of students selected for interview and lung function tests was produced and provided to each head teacher. The head teacher was asked to provide information on the weight and height of the students where parents did not provide this information in the questionnaires. If the head teachers were unable to provide the requested information, the weight and height of the students was measured and recorded by the nurses or the author for subsequent statistical analysis.

iv) Lung function measurements were conducted on selected asthmatic and non-asthmatic school children. The measurements were supervised by the author and two senior nurses from Chiang Mai University Hospital (Maharaj Nakorn Chiang Mai Hospital). Each step of the lung function measurements conducted in this study is listed below;

a) The students who were selected to undergo lung function measurements [13 female declared non-asthmatics, 12 male declared non-asthmatics, 6 female declared asthmatics, and 14 male declared asthmatics (45 subjects in total)] were introduced to the tests using a mini-Wright peak flow meter and a MicroLoop spirometer (serial no. 1497) (Figure 4.1). The nurse then demonstrated how to blow into the devices. The criteria for selecting students for measurements included; i) no signs of cold, flu, coughing or wheezing before the measurements were conducted; ii) their presence at the school; iii) willingness to undergo the measurements. The author attempted to match age and sex between asthmatic and non-asthmatic (control) groups and similarity in height was also considered, but it was not always possible due to the absence of preferred students or their ill-health with upper respiratory tract infections (common cold or flu). Both sexes were in an age range from 6 to 12 years in both groups, with the exception of female asthmatic subjects that were unavailable for ages 7, 8, 9 and 12 years.

b) Age, weight and height of each student were recorded with weight and height recorded when the students wearing school uniforms, but without shoes. The age was expressed in years. Weight and height units were expressed in kilograms (kg) and centimetres (cm) respectively. The height was measured with feet together and standing as straight as possible with the eyes level.

c) Before exercise, each student was requested to blow as forcefully as possible into a Wright's peak flow meter three times and the best flow rate out of three attempts (L/min) was recorded. The procedure was as follows:

- The mouthpiece was thoroughly disinfected with methyl alcohol using sterilised cotton wool. The nurses wore disposable surgery gloves at all times during lung function measurements.
- The indicator of the peak flow meter was placed at the base of the scale.
- Each student was asked to stand up and take a deep breath.
- The peak flow meter was then placed in the mouth and the lips closed around the mouth piece.
- The student was asked to blow as forcefully as possible.
- The achieved PEF measurement was recorded in a data sheet.
- The process was then repeated two more times.
- The highest PEF value was selected.

d) The spirometry process was similar to PEF measurement, but the students were asked to blow a few seconds longer than for the PEF maneuver, until the device produced a peeping sound at the end of each measurement. After PEF measurement, each student was asked to practice blowing until they performed the new maneuver correctly. The same student was then requested to blow into a spirometer as hard as possible. The three best values of FVC and FEV_1 were automatically recorded by the device. Soft nose clips were originally used for the students, but it was found that unfamiliarity with these devices was distracting. Therefore the nurses gently squeezed the students' noses while blowing.

e) After the first FVC and FEV_1 measurement, each student ran a distance of 100-400 m, around an outdoor playground until fatigued (breathing heavily).

f) Post effort expiratory performance of each student was recorded on the spirometer soon after exercise.

g) Each student was rewarded with biscuits and milk when the measurements had been completed.

v) All data from the completed questionnaires and lung function measurements were statistically analysed using the SPSS software programme, version 11 (see Section 4.2.1).

Source: Numed Cardiac Diagnostics (2006) http://www.micromed.co.uk; and Medisave (2006) http://www.medisave.co.uk

Figure 4.1 MicroLoop Spirometer (left) and Mini-Wright Peak Flow Meter (right)

4.2.1 Statistical analysis

i) In order to investigate the difference of each disease variable between urban and suburban areas, the Chi-squared (χ^2) test was applied to the questionnaire data. This test can be used with data which are categorical such as the data from the ISAAC questionnaire (Steward, 2002). The significance level was set at p=0.05 and the null hypothesis was that there was no difference between urban and suburban areas. Applying SPSS to the data, the χ^2 test tabulates each variable into categories and p values are also computed. For this study, a p value from the Fisher's exact test was selected because the data is presented as 2x2 tables.

ii) Confidence intervals for the prevalence rates of asthma, rhinitis and atopic dermatitis among children between suburban and urban school areas were calculated based on the number of cases or events (McCandless and Oliva, 2002). With 100 or more cases, the 95% confidence interval can be calculated as:-

R+/- 1.96 [R/SQRT (y)]

where R is the prevalence rate, SQRT is 'the square root of' and y is the number of cases.

In this study, the number of cases of asthma, rhinitis and atopic dermatitis was less than 100 and the upper and lower confidence intervals were calculated by multiplying the prevalence rate by the appropriate factors given in Appendix 9 (factors for calculating 95% confidence intervals when the number of cases or events is less than 100) (Ventura *et al.*, 2000). The formula and the table are for a Poisson-distributed variable. The Poisson distribution is used where counts of random events are recorded per unit. For example, to calculate the confidence intervals for a prevalence rate (5.4%) of asthmatic children (N = 9) in suburban schools, the lower and upper factors from Appendix 6 are 0.45726 and 1.89831. The lower and upper confidence intervals are calculated as 5.4x0.45726 and 5.4x1.89831 which are 2.469204 (~ 2.5) and 10.250874 (~10.3), respectively.

iii) Logistic regression analysis was also applied to investigate the associations between the prevalence of asthma, rhinitis and eczema, and environmental factors such as the frequency of trucks passing the home area, breastfeeding history, diet, pets and cigarette smoking of family members. It is a multiple regression analysis, but with an outcome variable that is dichotomous and predictor (independent) variables that are continuous or categorical (Field, 2000). The multiple logistic regression model can be explained by the 'logit link' as follows:-

$$\text{Logit}\ (p) = \ln(p/(1-p)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$$

where $\beta_0, \ldots, \beta_n$ are coefficients; $X_1, \ldots, X_n$ are independent variables; p is a probability (e.g. experienced asthma); $p/(1-p)$ is odds (p is a probability of a symptom occurring and, in contrast, $1-p$ is for not occurring).

Logistic regression analysis is appropriate to conduct an exploratory investigation of the data from the ISAAC questionnaire survey because each outcome variable (i.e. diseases) is dichotomous (e.g. 0 = no symptom and 1 = ever experienced a symptom) and predictor variables (i.e. environmental factors) are categorical. For a forward stepwise method, the model that included only a constant was begun and then single variables with a significance value ($p < 0.05$) were added to the model. At each step, the variables in the model were examined to determine whether any should be removed. For the likelihood ratio that is used in conjunction with a forward stepwise method, if the removal of a variable makes a significant difference to how well the model fits the observed data, then that variable is retained. In contrast, if little difference is made to the model then that variable is rejected (Field, 2000). The backward method is opposite to the forward method, but uses the same removal criteria. It begins the model with all predictors or variables included. The variables can be removed from the model which remains fitting the observed data. Field (2000) recommended that the backward method was preferable to the forward method because of suppressor effects, which occur when a predictor has a significant effect but only when another variable is held constant. The forward selection is more likely to exclude predictors involved in suppressor effects. For this study, the entry p is .05 and the removal p is 0.10.

The food variables that were excluded from the logistic regression analysis are bread and cereal; pasta; butter; margarine; potatoes; and fast food/burgers, in order to reduce the numbers of variables for better logistic regression analysis. These are not common dietary components for children in Chiang Mai, particularly those from poor socio-economic backgrounds – as in this study. This can also be observed in Table 4.1 summarising the frequency and percentage of missing values for food variables. For example, about 10% of respondents failed to answer the questions about the frequency of fast food and margarine eaten by their child, and 8% of them failed to answer the question about butter. These food variables were, therefore, not included in logistic regression analysis

Table 4.1 Missing value analysis for food variables

		Missing	
Variable	N	**Count**	%
Meat	496	15	2.9
Seafood	498	13	2.5
Fruit	499	12	2.3
Vegetables	495	16	3.1
Pulses	494	17	3.3
Bread and cereal	482	**29**	**5.7**
Pasta	479	**32**	**6.3**
Rice	485	26	5.1
Butter	468	**43**	**8.4**
Margarine	458	**53**	**10.4**
Nuts	483	28	5.5
Potatoes	488	**23**	**4.5**
Milk	495	16	3.1
Eggs	493	18	3.5
Fastfood	454	**57**	**11.2**

Note: Food variables in bold were excluded from logistic regression analysis

4.2.2 Site Descriptions

Four state schools in 3 urban districts (Muang, Hang Dong, and Saraphi) and two state schools in a suburban district (Mae Rim) were selected for the study (Figures 4.3 – 4.8) (the perspective views and layouts of six schools were produced on commission by Ms. Jaree Jaimook for this PhD thesis). The two suburban schools, Ban Korn Tal (S1) and Wat Saimoon (S2), were used as control sites (Figure 4.2). These suburban schools were chosen from the ADMS-Urban output, which suggested that they were not located in air polluted areas. The schools selected were primary state schools in adjacent suburban villages in Mae Rim district, 16 km north of Chiang Mai city. They are located outside the city and far from major air pollution sources (e.g. roads with high traffic volume, major industrial activities, agricultural burning). Therefore, it is assumed that the school children in the two suburban schools were not exposed to excess air pollution – particularly from traffic and industries, during school hours. In addition, another reason for selecting the 2 suburban schools was that the number of students from either school singly were not enough for the questionnaire survey.

Wat Sri Potaram School (S3) is located on Highway 106, a 2-way narrow road with 2 lanes. The road traffic is normally congested during rush hours in the morning and evening due to its narrowness and high traffic volume. The traffic speed in rush hours is below 40 km/hr. Tao Bunruang (S4), Ban San Pasak (S5) and Ban Donpin (S6) Schools are located on Highway 108, a dual carriageway (2x2 lanes), normally busy throughout the day and in rush hours, traffic speed is normally below 60 km/hr. ADMS-Urban modelling indicated that children in these urban schools (S3 – S6) were prone to exposure to high concentrations of air pollutants, especially from traffic and industries (Chapter 2).

Information on each school is summarized in Table 4.2. All Schools have a centrally located rectangular playground and playing field with buildings (classrooms, toilets, etc.) on three sides with one side parallel to the adjacent road. In comparison, S4 and S6 are larger than S1 – S3 and S5, and have additional buildings beyond the initial layout common to all. Trees and shrubs are established on the perimeter of the playgrounds of all schools but S1 has a higher density of trees and shrubs.

Most students in the selected 6 schools come from poor socio-economic backgrounds. The occupations of their parents include farmers, construction workers, factory workers, and unskilled workers. Some are from hill-tribes who temporarily migrated into the city and sent their children to the schools because they would be provided with free education and food (pers. comm. Mr. Vorrakarn Touila). The state schools do not have air conditioned classrooms. In this study, it is assumed that outdoor air quality influences air quality in the classrooms. From a discussion with the head teachers of Ban Donpin and Tao Bunruang Schools, they agreed that there was an atmospheric dust problem in the school areas.

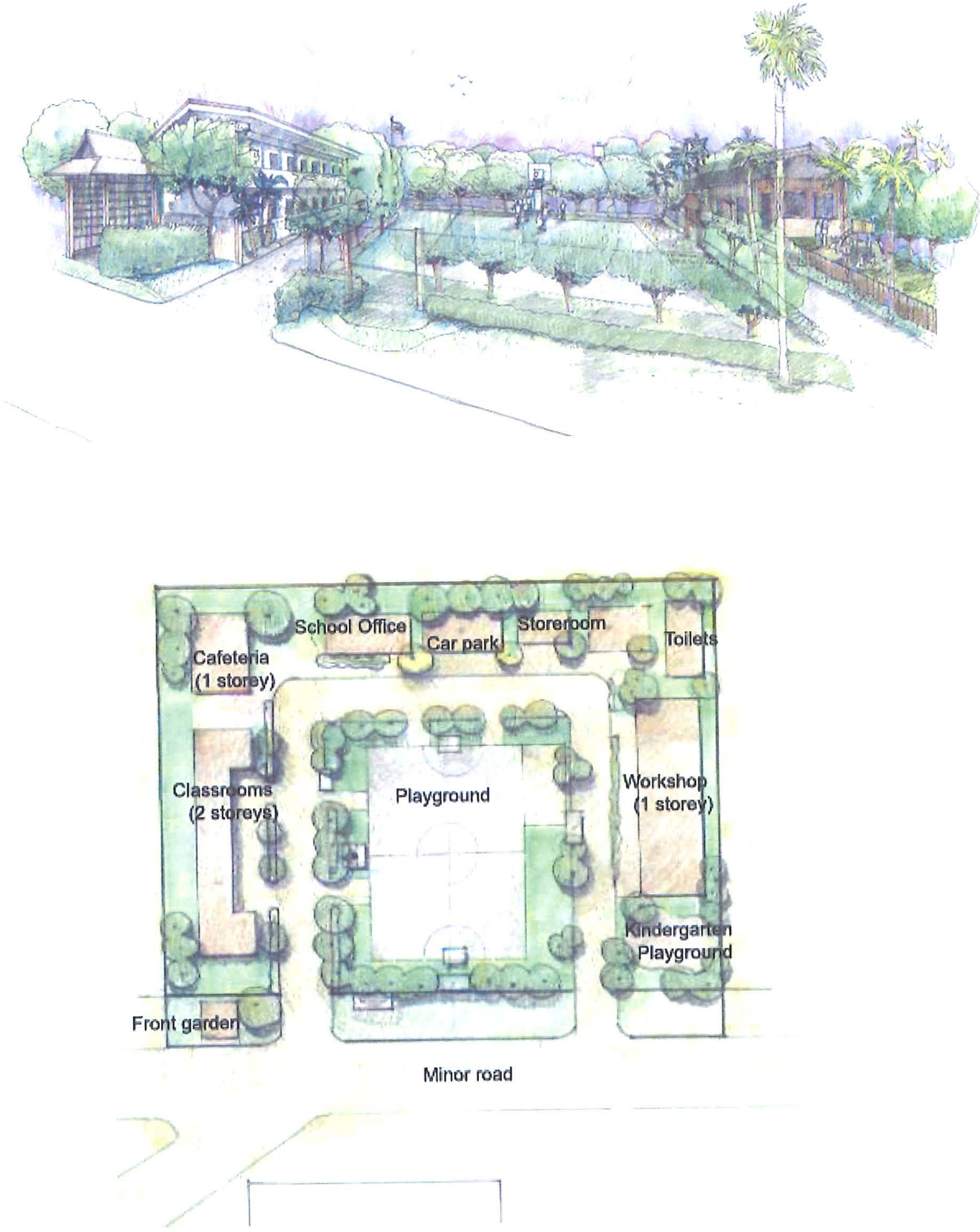
Table 4.2 School information

Ban Korn Tal School (Suburban) Level: Primary No. of students: 55 Area: 3000 m^2 Director: Mr. Vorrakarn Touila Address: Rimtai Sub-district, Mae Rim District, Chiang Mai 50180 Tel: 05329 8938	***Wat Saimoon School (Suburban)*** Level: Primary No. of students: 155 Area: 3000 m^2 Director: Mr. Somdej Waturanon Address: Rimtai Sub-district, Mae Rim District, Chiang Mai 50180 Tel: 05329 7413
Wat Sripotaram School (Urban) Level: Primary & Secondary No. of students: 174* Area: 3000 m^2 Director: Mr. Udom Chorfeung (until April 2004); Mr. Rugthai Sonkaew (from May 2005) Address: Saraphi Sub-district, Saraphi District, Chiang Mai 50140 Tel: 05332 1047	***Tao Bunruang School (Urban)*** Level: Primary No. of students: 85 Area: 3000 m^2 Director: Mr. Pongrak Premburi (until April 2004); Mr. Surajit Borisutsri (from May 2005) Address: Banwaen Sub-District, Hang Dong District, Chiang Mai 50230 Tel: 05344 1980
Ban San Pasak School (Urban) Level: Primary & Secondary No. of students: 562* Area: 4800 m^2 Director: Mr. Pigad Katipan Address: Nongkwai Sub-district, Hangdong District, Chiang Mai 50230 Tel: 05344 1818	***Ban Donpin School (Urban)*** Level: Primary & Secondary No. of students: 139* Area: 4000 m^2 Director: Mr. Pichai Pongjarearn (until May 2004); Mrs. Nittayaporn Kanchana (Acting Director from June 2004). Address: Maehea Sub-district, Muang District, Chiang Mai 50100 Tel: 05327 7011

Note: *primary level, November 2003.

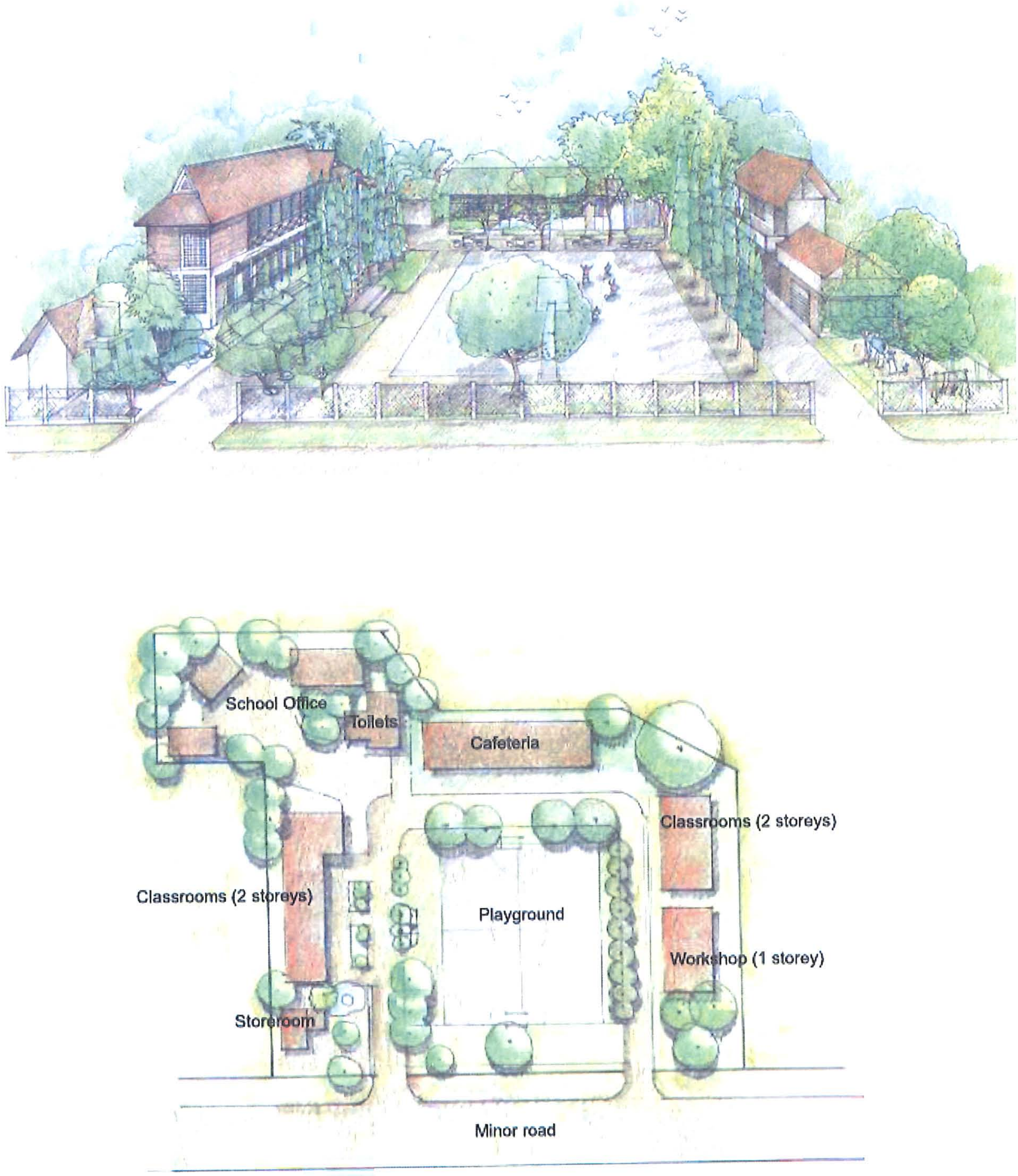
Illustrated by Khemmawit Sriyaraj

Figure 4.2 The locations of schools selected for the study of respiratory diseases and allergies among school children in Chiang Mai



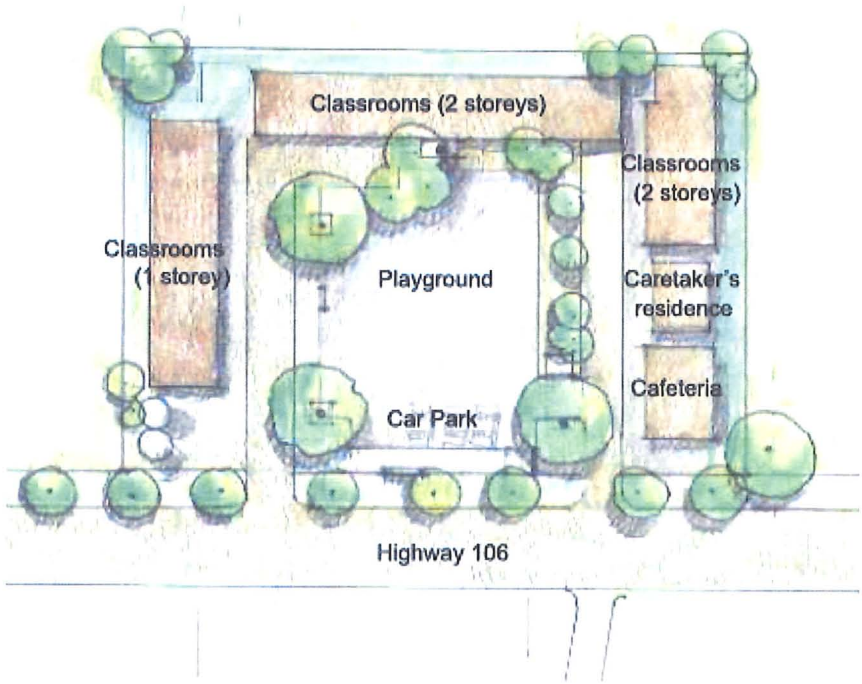
Illustrated by Jaree Jaimook

Figure 4.3 Perspective view and layout of Ban Korn Tal School (S1), Mae Rim District (suburban), Chiang Mai.



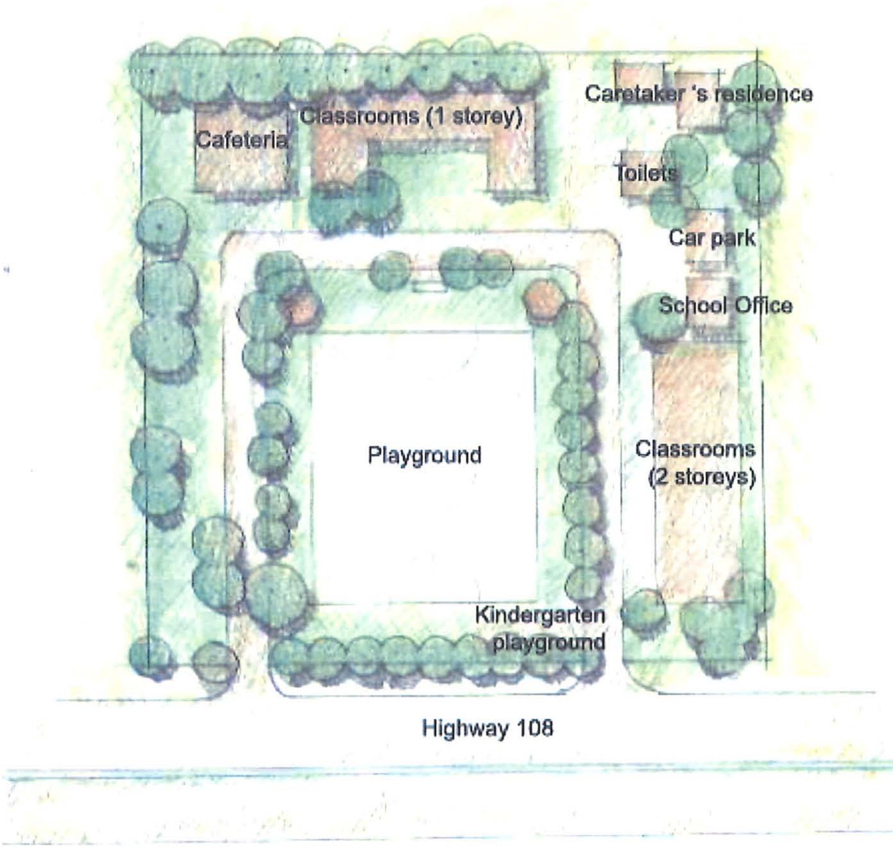
Illustrated by Jaree Jaimook

Figure 4.4 Perspective view and layout of Wat Saimoon School (S2), Mae Rim District (suburban), Chiang Mai.



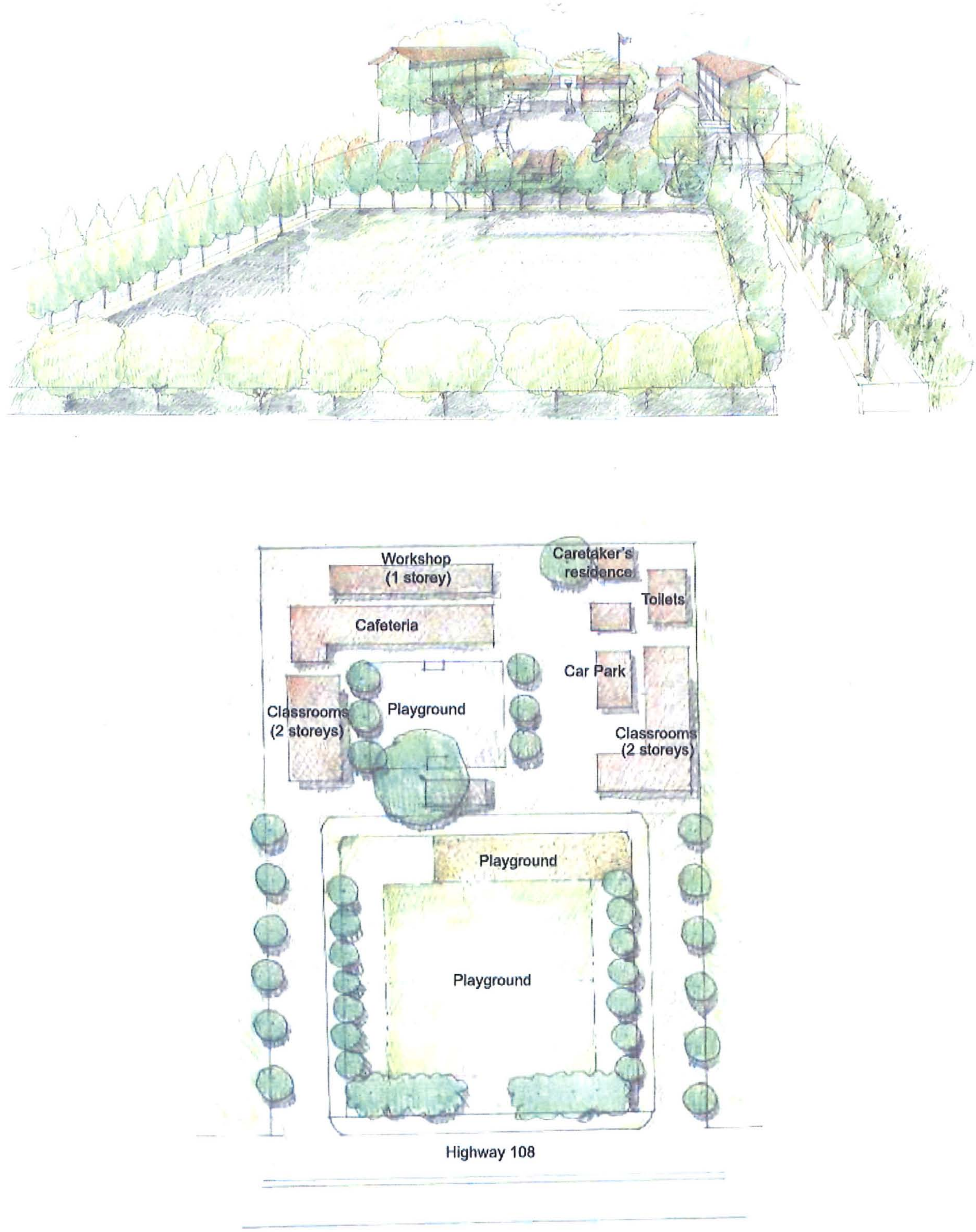
Illustrated by Jaree Jaimook

Figure 4.5 Perspective view and layout of Wat Sri Potaram School (S3), Saraphi District (urban), Chiang Mai.



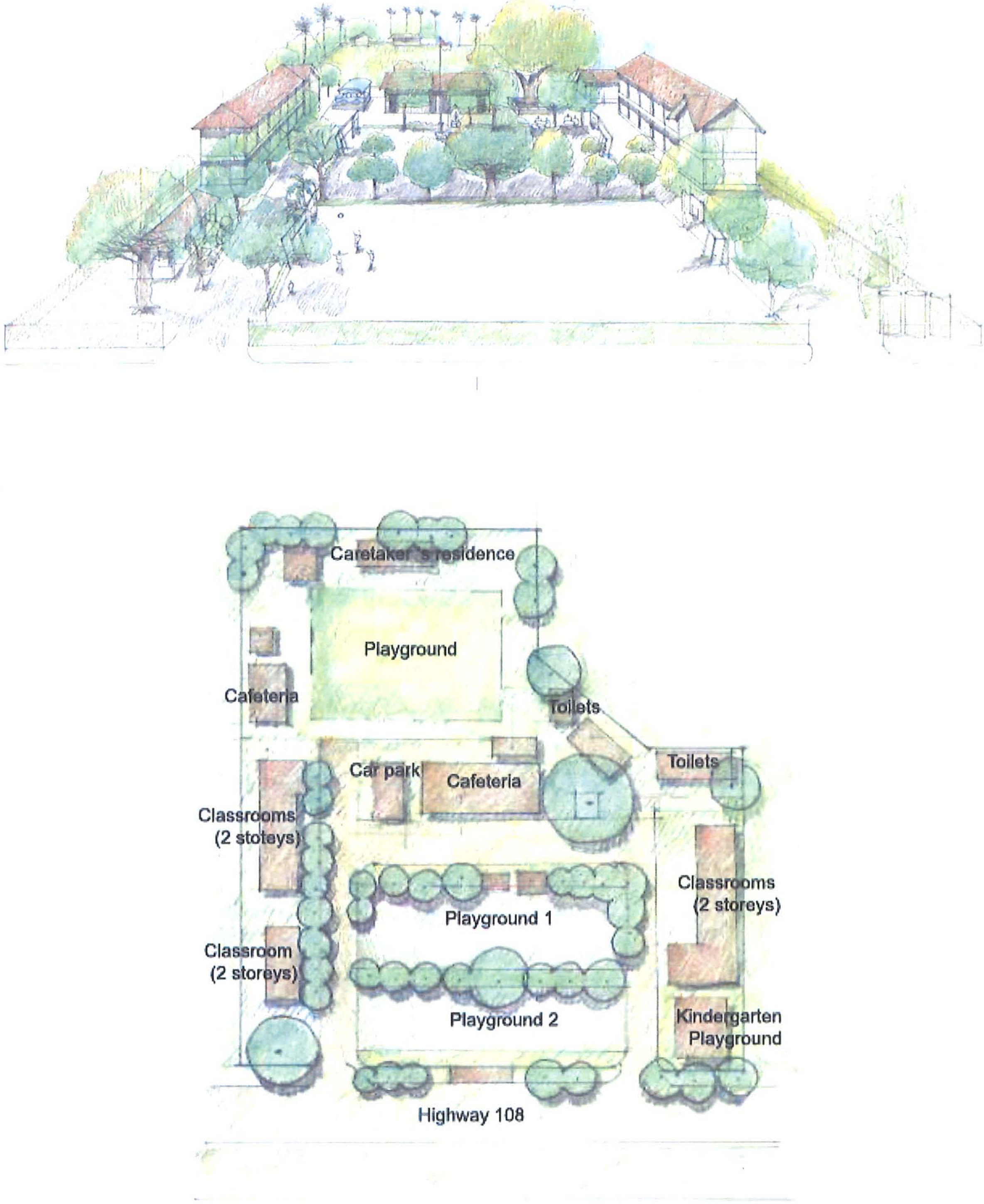
Illustrated by Jaree Jaimook

Figure 4.6 Perspective view and layout of Tao Bunruang School (S4), Hang Dong District (urban), Chiang Mai.



Illustrated by Jaree Jaimook

Figure 4.7 Perspective view and layout of Ban San Pasak School (S5), Hang Dong District (urban), Chiang Mai.



Illustrated by Jaree Jaimook

Figure 4.8 Perspective view and layout of Ban Donpin School (S6), Muang District (urban), Chiang Mai.

4.3 Results

4.3.1 Questionnaires

The returned questionnaires were collected from each school within a week of their distribution. Some questionnaires had incomplete answers and, if telephone numbers were given in the questionnaires, the parents were asked a few more questions in order to complete the questionnaires. Some students were interviewed directly to confirm their symptoms of asthma, rhinitis and eczema. The questionnaires, which were totally incomplete or half complete especially with regard to the questions about respiratory and allergic illnesses, were discarded. The numbers of questionnaires issued and returned from each school are summarised in Table 4.3. 511 (81.8%) usable questionnaires (of the 625 sent out) were returned and included in the statistical analysis.

Table 4.3 Numbers of questionnaires

School name	Delivered questionnaires	Returned questionnaires	Incomplete Questionnaires	Questionnaires used for SPSS
S1. Ban Korntal	60	51	2	49
S2. Wat Saimoon	160	125	15	117
S3. Wat Sri Potaram	100	93	2	91
S4. Tao Bunruang	85	76	10	67
S5. Ban San Pasak	120	104	5	99
S6. Ban Donpin	100	94	6	88
Total	**625** (100%)	**543** (86.9%)	**40** (6.4%)	**511** (81.8%)

Table 4.4 Descriptive statistics

Variable	N	Minimum	Maximum	Mean	Standard Deviation
Age	511	6	12	9.7	1.8
Weight (kg)	506	12.0	86.0	32.7	11.6
Height (cm.)	501	97.0	174.0	135.1	12.5
Birth weight (kg)	470	1.0	5.0	3.0	0.5

Descriptive statistics for all the children included in the survey are summarized in Table 4.4. Frequencies and percentages for potential confounders (i.e. general characteristics and living conditions; food variables) are summarized in Tables 4.5 and 4.6, respectively. Weight and height of each student were also monitored by the author if the information was not provided by the teachers. The reported age ranges between 6-12 years, weight 12-86 kg, height 97-174 cm, and birth weight 1-5 kg. Birth weights of 41 students were not reported by the parents who may have forgotten the information. Furthermore, other potential confounders include sex, race, district, fuel used for cooking, use of air conditioner or fan, use of paracetamol and antibiotics, number of older and younger siblings, level of education of mother, country of birth, frequency of trucks passing home area, breastfeeding history, cats/dogs as pets, contact with farm animal, and cigarette smoking for both mother and father.

Table 4.5 General characteristics and living conditions reported for all children (N = 511)

Characteristic & living condition		Frequency	%
Sex (n = 511)	Male	262	51.3
	Female	249	48.7
Race (n = 511)	Thai	504	98.6
	Others	7	1.4
School location (n = 511)	Urban	345	67.5
	Suburban	166	32.5
Fuel used for cooking (n = 506)	Electricity	9	1.8
	Gas	292	57.7
	Open fires	77	15.2
	Open fires & gas	99	19.6
	Electricity & gas	11	2.2
	Open fires & electricity	1	0.2
	All three fuels	16	3.2
Use of air conditioner/fan (n = 507)	Air conditioner	3	0.6
	Electric fan	442	87.2
	Both	9	1.8
	Do not use both	53	10.4
Use of paracetamol & antibiotics	Paracetamol taken in the 1st year of life (n =495)	282	57.0
	Paracetamol taken in the past 12 months		
	Once a year	262	52.4
	Once a month	152	30.4
	Antibiotics taken in the 1st year of life (n = 497)	295	59.4
Older brothers/sisters (n = 507)	None	281	55.4
	One	184	36.3
	More than one	42	8.3
Younger brothers/sister (n = 507)	None	368	72.6
	One	122	24.1
	More than one	17	3.3
Country of birth (n = 511)	Thailand	509	99.6
	Other countries	2	0.4
Mother's education level (n = 497)	Primary	352	70.8
	Secondary	115	23.1
	College/university	30	6.1
Frequency of trucks passing home area (n = 509)	Never	103	20.3
	Seldom	164	32.2
	Frequently through the day	131	25.7
	Almost the whole day	111	21.8
Breastfeeding (n = 508)	Breastfed child	418	82.3
Cats/dogs	Cats during the 1st year of child's life (n = 505)	55	10.9
	Cats in the past 12 months (n = 511)	136	26.6
	Dogs during the 1st year of child's life (n = 511)	184	36.0
	Dogs in the past 12 months (n = 510)	243	47.6
Farm animals	Child contacted with farm animals (n = 509)	140	27.5
	Child's mother contacted with farms animal while being pregnant of this child (n = 505)	88	17.4
Cigarette smoking	Mother smoking cigarettes (n = 509)	23	4.5
	Mother smoked during the 1st year of child's life (n = 507)	27	5.3
	Father smoking cigarettes (n = 509)	251	49.3

Table 4.6 Food variables

Variable		Frequency	%
1. Meat	- Never or occasionally	39	7.6
	- Once or twice a week	174	34.1
	- ≥ 3 times a week	283	55.4
2. Seafood (incl. fish)	- Never or occasionally	99	19.4
	- Once or twice a week	276	54.0
	- ≥ 3 times a week	123	24.1
3. Fruit	- Never or occasionally	53	10.4
	- Once or twice a week	191	37.4
	- ≥ 3 times a week	255	49.9
4. Vegetable (green and root)	- Never or occasionally	84	16.4
	- Once or twice a week	205	40.1
	- ≥ 3 times a week	206	40.3
5. Pulses (peas, beans, lentils)	- Never or occasionally	133	26.0
	- Once or twice a week	227	44.4
	- ≥ 3 times a week	134	26.2
6. Bread and cereal	- Never or occasionally	182	35.6
	- Once or twice a week	183	35.8
	- ≥ 3 times a week	117	22.9
7. Pasta	- Never or occasionally	223	43.6
	- Once or twice a week	168	32.9
	- ≥ 3 times a week	88	17.2
8. Rice	- Never or occasionally	16	3.1
	- Once or twice a week	68	13.3
	- ≥ 3 times a week	401	78.5
9. Butter	- Never or occasionally	335	65.6
	- Once or twice a week	93	18.2
	- ≥ 3 times a week	40	7.8
10. Margarine	- Never or occasionally	371	72.6
	- Once or twice a week	66	12.9
	- ≥ 3 times a week	22	4.3
11. Nuts	- Never or occasionally	160	31.3
	- Once or twice a week	230	45.0
	- ≥ 3 times a week	93	18.2
12. Potatoes	- Never or occasionally	189	37.0
	- Once or twice a week	217	42.5
	- ≥ 3 times a week	82	16.0
13. Milk	- Never or occasionally	17	3.3
	- Once or twice a week	142	27.8
	- ≥ 3 times a week	336	65.8
14. Eggs	- Never or occasionally	15	2.9
	- Once or twice a week	156	30.5
	- ≥ 3 times a week	322	63.0
15. Fast food/burgers	- Never or occasionally	332	65.0
	- Once or twice a week	81	15.9
	- ≥ 3 times a week	41	8.0

Table 4.7 Prevalence and prevalence rate of children with wheezing, rhinitis and rash symptoms

Symptom	Suburban		Urban		Total		p^c
	Prev.[a]	**PR**[b]	**Prev.**[a]	**PR**[b]	**Prev.**[a]	**PR**[b]	
Wheezing							
Wheeze ever	10/166	6.0	35/345	10.1	45/511	8.8	0.136
Wheeze in the past 12 months	9/166	**5.4**	19/345	**5.5**	28/511	**5.5**	1.000
Asthma attacks in the past 12 months							
$\geq$ 4 attacks	2/9	36.8	12/19	63.2	14/28	50.0	0.103
Wheeze disturbing sleep	3/9	33.3	16/19	84.2	19/28	67.9	0.036*
Severe wheeze limiting speech	1/9	11.1	11/19	57.9	12/28	42.9	0.039*
Exercise wheeze	3/166	1.8	18/345	5.2	21/511	4.1	0.094
Night cough	15/166	9.0	41/345	11.9	56/511	11.0	0.368
Ever had asthma	10/166	6.0	32/345	9.3	43/511	8.4	0.233
Rhinitis							
Rhinitis ever	39/166	23.5	98/345	28.4	137/511	26.8	0.286
Rhinitis in the past 12 months	26/166	**15.7**	84/345	**24.3**	110/511	**21.5**	0.029*
with itchy-watery eyes	5/25	20.0	35/84	41.7	40/109	36.7	0.004*
interfering with daily activities	10/25	40.0	23/80	28.8	33/105	31.4	0.328
Hay fever ever	23/166	**13.9**	80/345	**23.2**	103/511	**20.2**	0.014*
Rash							
Rash ever	27/166	16.3	54/345	15.7	81/511	15.9	0.897
Rash in the past 12 months	17/166	10.2	46/345	13.3	63/511	12.3	0.389
Rash at flexural areas	12/166	**7.2**	43/345	**12.5**	55/511	**10.8**	0.093
cleared within 12 months	11/16	68.8	26/45	57.8	37/61	60.7	0.557
night waking <1 per week	6/17	35.3	20/44	45.5	26/61	42.6	0.620
night waking $\geq$1 per week	5/17	29.4	8/44	18.2	13/61	21.3	0.620
Eczema ever	25/166	**15.1**	52/345	**15.1**	77/511	**15.1**	1.000

Note: [a] Prevalence – the prevalence of a disease is the number of cases in a defined population at a specified point in time (WHO, 1993). [b] Prevalence rate – the prevalence rate is expressed as cases per 100 population. [c]The p values from χ^2 Fisher's exact test between urban and suburban areas. *The difference of the symptom between the two areas is significant ($p < 0.05$). Symptoms in **bold** are for diagnosis of asthma, rhinitis and atopic dermatitis, respectively (Trakultivakorn, 1999).

Table 4.7 shows the comparison between the schools in urban and suburban areas with respect to asthma, rhinitis and rash symptoms. The percentage of rhinitis in the past 12 months was significantly higher in the urban schools than in the suburban schools (24.3% vs. 15.7%), as was the prevalence of hay fever (23.2% vs. 13.9%). The prevalence of rash in the past 12 months (13.3% vs. 10.2%) and atopic dermatitis (12.5% vs. 7.2%) in the urban schools was higher than suburban schools, although the differences were not significant.

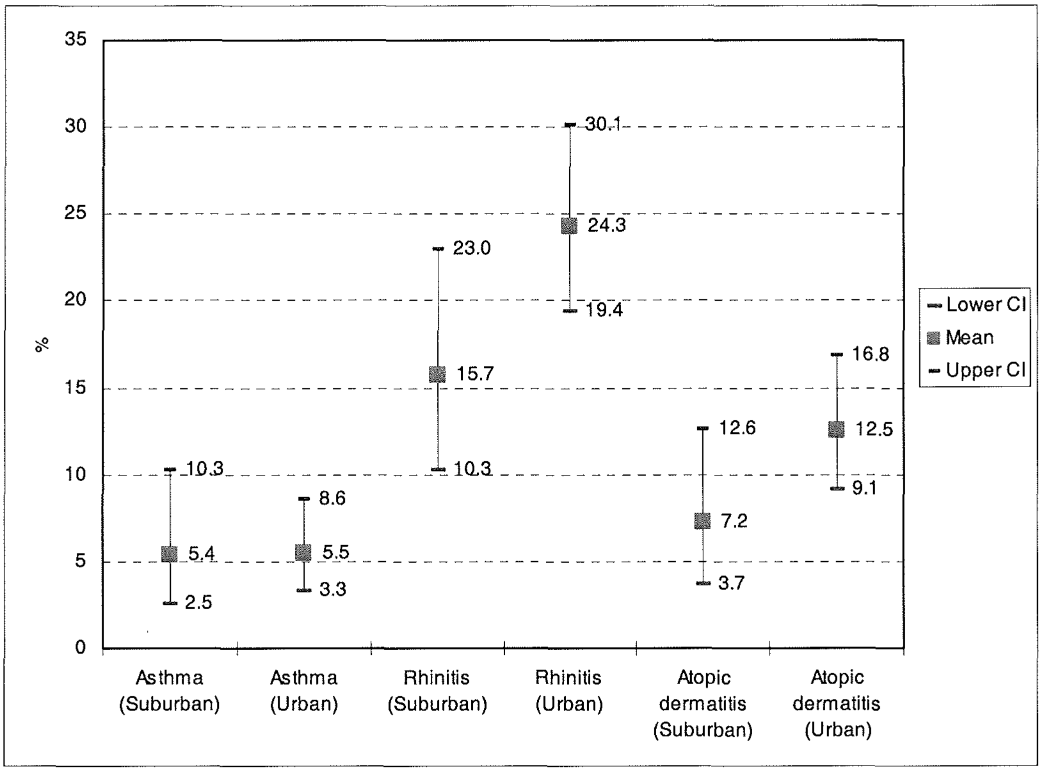


Figure 4.9 Prevalence rates (%) and 95% confidence intervals of asthma, rhinitis and atopic dermatitis among children resident in suburban and urban school areas

Figure 4.9 shows the prevalence rates and confidence intervals (CI) for asthma, rhinitis and atopic dermatitis among children attending suburban and urban schools. The prevalence rates of asthma were approximately 5.5% and were similar in both areas. The prevalence rates of rhinitis in suburban and urban schools were 15.7% (CI = 10.3–23.0) and 24.3% (CI = 19.4 – 30.1), respectively. For atopic dermatitis, the prevalence rates in suburban and urban schools were 7.2% (CI = 3.7–12.6) and 12.5% (CI = 9.1–16.8) respectively. The prevalence rates of asthma, rhinitis and eczema and related symptoms in each school are summarised in Table 4.8. The highest prevalence rates of wheezing in the past 12 months (10.2%) and asthma (ever) were found in School 1 (Ban Korn Tal), a suburban school, but the highest exercise wheeze rate (7.7%) was found in School 3 (Wat Sripotaram), an urban school. School 6 (Ban Donpin) had the highest rates of children who suffered from night cough (15.9%), rhinitis in the past 12 months (31.8%), itchy and watery eyes (13.6%) and hay fever (30.7%). School 3 (Wat Sripotaram) located in an urban area has highest prevalence of rash in the past 12 months (19.8%), rash at flexural areas or atopic dermatitis (18.7%) and eczema (19.8%). The symptoms that are statistically different among 6 schools include: rhinitis ever; rhinitis in the past 12 months; itchy – watery eyes; rash at flexural areas.

Table 4.8 Prevalence rates of wheezing, rhinitis and rash symptoms in each school

Health characteristic	**Prevalence rate (%)**						***p*-value†**
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	
Wheeze ever	12.2	3.4	11.0	**13.4**	8.1	9.1	0.133
Wheeze in the past 12 months	**10.2**	3.4	7.7	6.0	3.0	5.7	0.380
Ever had asthma	**12.2**	3.4	11.0	11.9	6.1	9.1	0.135
Exercise wheeze	0.0	2.6	**7.7**	4.5	3.0	5.7	0.267
Night cough	8.2	9.4	11.0	10.4	10.1	**15.9**	0.747
Rhinitis ever	22.4	23.9	**36.3**	23.9	18.2	35.2	0.033*
Rhinitis in the past 12 months	16.3	15.4	30.8	20.9	14.1	**31.8**	0.006*
Itchy – watery eyes	0.0	4.3	8.8	10.4	8.1	**13.6**	0.030*
Hay fever ever	14.3	13.7	23.1	20.9	18.2	**30.7**	0.061
Rash ever	8.2	19.7	19.8	11.9	9.1	**21.6**	0.051
Rash in the past 12 months	6.1	12.0	**19.8**	9.0	7.1	17.0	0.050
Rash at flexural areas	4.1	8.5	**18.7**	7.5	7.1	15.9	0.028*
Eczema ever	6.1	18.8	**19.8**	10.4	10.1	19.3	0.066

Note: S1 = Ban Korn Tal School; S2 = Wat Saimoon; S3 = Wat Sripotaram; S4 = Tao Bunruang; S5 = Ban San Pasak; and S6 = Ban Donpin. The maximum prevalence rate of each characteristic is highlighted in bold.
† *p*-value based on χ^2 Fisher's exact test. *Significant

Due to there being, in total, 39 predictor variables (Table 4.9), a forward stepwise logistic regression method was, therefore, employed. This was followed by the application of a backward method. All variables that were selected by the forward method for any of the outcome variables were then input to a backward regression for each outcome variable. Table 4.10 shows the variables finally retained after the forward and then backward elimination. For the probability for stepwise used in this analysis, the entry p was 0.05 and the removal p was 0.10 in both forward and backward stepwise. Moreover, none of the environmental variables were found to be associated with wheeze ever and wheeze in the past 12 months, because there were no environmental variables selected in the forward stepwise, and none retained in the backward stepwise analysis.

Table 4.9 Predictor variables brought in by the forward elimination of the logistic regression analysis

Predictor variables for logistic regression analysis	Rhinitis Ever	Rhinitis Past 12 m.	Hay fever	Rash Ever	Rash Past 12 m.	Atopic dermatitis	Eczema
Environmental variables							
Age							
Sex							
Physical activities		✓	✓				
Watching TV							
Fuel used for cooking							
Use of air conditioner/electric fan							
Paracetamol taken in 1st year of child's life							
Paracetamol taken in the past 12 months	✓	✓	✓				
Antibiotics taken in 1st year of child's life				✓	✓	✓	✓
Birth place							
School location (urban vs. suburban)		✓	✓			✓	
Mother's education level							
Trucks passing home area	✓			✓	✓	✓	✓
Breast feeding							
Cats during 1st year of child's life	✓	✓	✓	✓	✓	✓	✓
Cats in the past 12 months		✓	✓	✓	✓		✓
Dogs during 1st year of child's life		✓	✓	✓	✓		✓
Dogs in the past 12 months		✓	✓	✓	✓		✓
Child contacted with farm animals							
Contact with farm animals during pregnancy		✓	✓	✓	✓	✓	✓
Cigarette smoking (mother)	✓	✓	✓	✓	✓		✓
Cigarette smoking (mother) during pregnancy	✓						
Cigarette smoking (father)	✓						
Smokers in the house							
Older siblings							
Younger siblings							
Quantitative variables							
Weight							
Height							
Birth weight					✓	✓	✓
Years lived in Thailand							
Food variables							
Meat							
Seafood							
Fruit							
Vegetables							
Pulses							
Rice							
Nuts				✓	✓	✓	✓
Milk							
Eggs							

Note: All 39 predictor variables were input to a forward stepwise selection for each outcome variable (e.g. symptoms and diseases). ✓ Variables brought in by the forward elimination.

Table 4.10 Predictor variables retained after the backward elimination (after pre-selected by the forward elimination) of the logistic regression analysis

Predictor variables for logistic regression analysis	Rhinitis		Hay fever	Rash		Atopic dermatitis	Eczema
	Ever	Past 12 m.		Ever	Past 12 m.		
Environmental variables							
Age							
Sex							
Physical activities							
Watching TV							
Fuel used for cooking							
Use of air conditioner/electric fan							
Paracetamol taken in 1st year of child's life							
Paracetamol taken in the past 12 months	✓	✓	✓				
Antibiotics taken in 1st year of child's life				✓	✓	✓	✓
Birth place							
School location (urban vs. suburban)		✓	✓			✓	
Mother's education level							
Trucks passing home area	✓			✓	✓	✓	✓
Breast feeding							
Cats during 1st year of child's life	✓					✓	
Cats in the past 12 months				✓			✓
Dogs during 1st year of child's life				✓	✓		✓
Dogs in the past 12 months							
Child contacted with farm animals							
Contact with farm animals during pregnancy		✓	✓				
Cigarette smoking (mother)				✓	✓		✓
Cigarette smoking (mother) during pregnancy							
Cigarette smoking (father)							
Smokers in the house							
Older siblings							
Younger siblings							
Quantitative variables							
Weight							
Height							
Birth weight				✓	✓	✓	
Years lived in Thailand							
Food variables							
Meat							
Seafood							
Fruit							
Vegetables							
Pulses							
Rice							
Nuts				✓	✓	✓	✓
Milk							
Eggs							

Note: ✓ Variables brought in by the backward elimination (after pre-selected by the forward elimination).

Attempts were also made to input the 6 schools as variables into the logistic analysis, however, this made little difference, except for rhinitis ever and atopic dermatitis. Use of the '6 schools' variable pushed a non-significant variable out of the model, but, the '6 schools' variable itself was non-significant for both models. Moreover, the significant variables ($p < 0.05$) remained unchanged. It follows that for this study attention was given to the 2 divided groups of students (i.e. 'urban' and 'suburban' school areas) during analysis.

Tables 4.11–4.17 summarise the results of the logistic regression analysis with respect to the associations of the health outcomes with possible environmental (confounding) variables. In Table 4.11, rhinitis (ever) was associated with paracetamol taken in the past 12 months ($p < 0.0001$) and trucks passing home area ($p = 0.047$). Rhinitis in the past 12 months (Table 4.12) was associated with paracetamol taken in the past 12 months ($p < 0.0001$) and contact of the child's mother with farm animals while being pregnant with this child ($p = 0.012$). Hay fever was associated with paracetamol taken in the past 12 months ($p = 0.001$), contact of the child's mother with farm animals while being pregnant ($p = 0.003$), and school location ($p = 0.046$) (Table 4.13). Moreover, for each of these endpoints the odds ratio increased with increasing exposure to paracetamol. Such an increase would be expected if paracetamol was causal.

Table 4.11 Associations of rhinitis (ever) with potential environmental factors

Potential environmental factors	Odds ratio (95% CI)	*p*-value†	*p*-value††
Paracetamol taken in the past 12 months			**<0.0001***
Never	1.00**		
Once per year	1.86 (0.94 – 3.69)	0.076	
Once per month	3.95 (1.96 – 7.99)	<0.0001*	
Frequency of truck passing the home area			**0.047***
Never	1.00**		
Seldom	1.31(0.73 – 2.37)	0.368	
Frequently through the day	0.75 (0.39 – 1.43)	0.379	
Almost the whole day	1.71 (0.91 – 3.22)	0.097	
Having cats during the first year of child's life			**0.091**
No	1.00**		
Yes	1.71 (0.92 – 3.17)	0.091	

Note: **Baseline category. † *p*-value based on χ^2 likelihood ratio test. †† ***p*-value in bold** for the overall effect of the factor. *Significant.

Table 4.12 Associations of rhinitis (in the past 12 months) with potential environmental factors

Potential environmental factors	Odds ratio (95% CI)	*p*-value†	*p*-value††
Paracetamol taken in the past 12 months			**<0.0001****
Never	1.00**		
Once per year	1.45 (0.69 – 3.08)	0.327	
Once per month	3.52 (1.65 – 7.50)	0.001*	
Child's mother in contact with farm animals while being pregnant with this child			**0.012***
No	1.00**		
Yes	2.01 (1.17 – 3.47)	0.012*	
School location			**0.078**
Suburban	1.00**		
Urban	1.58 (0.95 – 2.63)	0.078	

Note: **Baseline category. *p*-value based on χ^2 likelihood ratio test. ††***p*-value in bold** for the overall effect of the factor. *Significant.

Table 4.13 Associations of hay fever with potential environmental factors

Potential environmental factors	Odds ratio (95% CI)	*p*-value†	*p*-value††
Paracetamol taken in the past 12 months			**0.001***
Never	1.00**		
Once per year	1.19 (0.57 – 2.47)	0.645	
Once per month	2.77 (1.32 – 5.81)	0.007*	
Child's mother in contact with farm animals while being pregnant with this child			**0.003***
No	1.00**		
Yes	2.31 (1.34 – 3.98)	0.003*	
School location			**0.046***
Suburban	1.00**		
Urban	1.71 (1.01 – 2.90)	0.046*	

Note: **Baseline category. *p*-value based on χ^2 likelihood ratio test. ††***p*-value in bold** for the overall effect of the factor. *Significant.

Table 4.14 Associations of rash (ever) with potential environmental factors

Potential environmental factors	Odds ratio (95% CI)	p-value†	p-value††
Antibiotics taken in first year of child's life			**0.002***
No	1.00**		
Yes	2.92 (1.49 – 5.69)	0.002*	
Frequency of truck passing the home area			**0.005***
Never	1.00**		
Seldom	2.58 (0.88 – 7.54)	0.083	
Frequently through the day	5.86 (2.02 – 17.00)	0.001*	
Almost the whole day	4.09 (1.37 – 12.26)	0.012*	
Nuts eaten in the past 12 months			**0.016***
Never or occasionally	1.00**		
1 – 2 times/week	1.05 (0.55 – 2.01)	0.890	
≥ 3 times/week	2.73 (1.27 – 5.88)	0.010*	
Birth weight	0.63 (0.38 – 1.05)	0.075	**0.075**
Maternal cigarette smoking			**0.001***
No	1.00**		
Yes	5.85 (1.97 – 17.35)	0.001*	
Having dogs during the first year of child's life			**0.004***
No	1.00**		
Yes	2.32 (1.31 – 4.10)	0.004*	
Having cats in the past 12 months			**0.072**
No	1.00**		
Yes	1.73 (0.95 – 3.14)	0.072	

Note: **Baseline category. p-value based on χ^2 likelihood ratio test. ††***p*-value in bold** for the overall effect of the factor. *Significant.

For rash (ever) (Table 4.14), five environmental factors achieved significance; antibiotics taken in the first year of child's life (p = 0.002); frequency of trucks passing the home area (p = 0.005); nuts eaten in the past 12 months (p = 0.016); maternal smoke (p = 0.001) and having dogs during the first year of child's life (p = 0.004).

Table 4.15 Associations of rash (in the past 12 months) with potential environmental factors

Potential environmental factors	**Odds ratio (95% CI)**	***p*-value†**	***p*-value††**
Antibiotics taken in first year of child's life			**<0.0001***
No	1.00**		
Yes	4.83 (2.09 – 11.20)	<0.0001*	
Frequency of truck passing the home area			**0.019***
Never	1.00**		
Seldom	3.36 (0.91 – 12.45)	0.070	
Frequently through the day	6.40 (1.72 – 23.76)	0.006*	
Almost the whole day	6.34 (1.69 – 23.80)	0.006*	
Nuts eaten in the past 12 months			**0.013***
Never or occasionally	1.00**		
1 – 2 times/week	0.77 (0.37 – 1.58)	0.473	
≥ 3 times/week	2.52 (1.11 – 5.71)	0.027*	
Maternal cigarette smoking			**0.005***
No	1.00**		
Yes	5.64 (1.70 – 18.71)	0.005*	
Having dogs during the first year of child's life			**0.006***
No	1.00**		
Yes	2.44 (1.30 – 4.58)	0.006*	
Birth weight	0.60 (0.34 – 1.06)	0.078	**0.078**

Note: **Baseline category. *p*-value based on χ^2 likelihood ratio test. ††***p*-value in bold** for the overall effect of the factor. *Significant.

For rash in the past 12 months (Table 4.15), the significant environmental factors included the same five factors as for rash (ever) which include antibiotics ($p < 0.0001$), trucks ($p = 0.019$), nuts ($p = 0.013$), maternal smoke ($p = 0.005$) and having dogs in the first year of life ($p = 0.006$). The environmental factors that are likely to be associated with atopic dermatitis are antibiotics ($p < 0.0001$) and living with cats during the first year of life ($p = 0.010$) (Table 4.16). For eczema, six environmental factors achieved significance; antibiotics ($p = 0.001$); trucks ($p = 0.02$); dogs in the first year of life ($p = 0.018$); cats in the past 12 months ($p = 0.041$); maternal smoke ($p = 0.001$); and nuts taken in the past 12 months ($p = 0.036$) (Table 4.17).

Table 4.16 Associations of atopic dermatitis with potential environmental factors

Potential environmental factors	Odds ratio (95% CI)	p-value†	p-value††
Antibiotics taken in first year of child's life			**<0.0001***
No	1.00**	<0.0001*	
Yes	5.51 (2.21 – 13.77)		
Cats in the house during the first year of child's life			**0.010***
No	1.00**	0.010*	
Yes	2.96 (1.30 – 6.76)		
Frequency of truck passing the home area			**0.141**
Never	1.00**		
Seldom	2.77 (0.75 – 10.23)	0.128	
Frequently through the day	4.07 (1.09 -15.19)	0.037*	
Almost the whole day	4.26 (1.13 – 16.07)	0.033*	
Nuts eaten in the past 12 months			**0.080**
Never or occasionally	1.00**		
1 – 2 times/week	0.72 (0.33 – 1.54)	0.393	
≥ 3 times/week	1.84 (0.80 – 4.24)	0.153	
School location			**0.079**
Suburban	1.00**		
Urban	1.97 (0.93 – 4.19)	0.079	
Birth weight	0.58 (0.31 – 1.06)	0.077	**0.077**

Note: **Baseline category. p-value based on χ^2 likelihood ratio test. ††***p*-value in bold** for the overall effect of the factor. *Significant.

Table 4.17 Associations of eczema with potential environmental factors

Potential environmental factors	Odds ratio (95% CI)	p-value†	p-value††
Antibiotics taken in first year of child's life			**0.001***
No	1.00**	0.001*	
Yes	3.22 (1.61 – 6.46)		
Frequency of truck passing the home area			**0.020***
Never	1.00**		
Seldom	2.39 (0.82 – 7.01)	0.112	
Frequently through the day	4.36 (1.50 – 12.67)	0.007*	
Almost the whole day	4.33 (1.47 – 12.78)	0.008*	
Having dogs during the first year of child's life			**0.018***
No	1.00**		
Yes	2.00 (1.13 – 3.56)	0.018*	
Having cats in the past 12 months			**0.041***
No	1.00**		
Yes	1.87 (1.03 – 3.40)	0.041*	
Maternal cigarette smoking			**0.001***
No	1.00**		
Yes	6.78 (2.27 – 20.27)	0.001*	
Nuts eaten in the past 12 months			**0.036***
Never or occasionally	1.00**		
1 – 2 times/week	1.27 (0.65 – 2.48)	0.478	
≥ 3 times/week	2.71 (1.23 – 5.95)	0.013*	

Note: **Baseline category. p-value based on χ^2 likelihood ratio ††***p*-value in bold** for the overall effect of the factor. *Significant.

In order to test the model fit, the log-likelihood statistic was considered for each outcome variable. The final -2xlog-likelihoods (-2*LL*) was compared with the initial -2*LL* (when there was only constant in the model). -2*LL* value should be less than the value when only the constant was included in the model (Field, 2000). The results of log-likelihood ratio test and the chi-squared (χ^2) value for each prediction for each outcome variable are summarised in Table 4.18. From this analysis, the final -2*LL* was smaller than the initial -2*LL*, for each model of outcome variable. In addition, the χ^2 value for each prediction was significant (all have *p* value less than 0.0001), therefore, overall, each model predicted the outcome variable significantly better than the case was with only the constant included.

Table 4.18 The results of log-likelihood ratio test and the chi-squared (χ^2) value for each prediction for each outcome variable

Outcome variable	Initial -2*LL*	Final -2*LL*	χ^2	*p*
Rhinitis (ever)	570.367	537.891	32.477	<0.0001
Rhinitis (in the past 12 months)	496.808	468.701	28.107	<0.0001
Hay fever	481.258	454.234	27.024	<0.0001
Rash (ever)	379.477	323.657	55.819	<0.0001
Rash (in the past 12 months)	325.529	271.562	53.967	<0.0001
Atopic dermatitis	292.978	250.673	42.305	<0.0001
Eczema	369.358	317.491	51.867	<0.0001

Note: χ^2 = Difference between the final -2*LL* and initial -2*LL*.

4.3.2 Lung Function Tests

The results of the lung function tests are shown in Tables 4.19 and 4.20. These present data for 19 and 26 putative asthmatics and non-asthmatics, respectively. The peak expiratory flow (PEF) in the normal subjects ranged from 140 – 400 L/min, with an average of 265.8 L/min. In the asthmatics, the PEF ranged from 140 – 350 L/min with an average of 258.0 L/min. The box plot of PEF shows that the non-asthmatic group had a slightly higher median peak flow than the asthmatic group (Figure 4.10). For the forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) in normal subjects, before exercise, ranged from between 0.97–2.85 L/sec and 1.09–3.1 L, respectively. In asthmatics, the FEV_1 and FVC range from 0.71–2.26 L/sec and 0.85–2.57 L, respectively. Before exercise, approximately 55% of asthmatics and 30% of non-asthmatics had FEV_1/FVC ratios lower than 90%. Air flow limitation was found in 2 male asthmatics that had measured ratios of 72% and 78% before exercise and 75% and 71% after exercise. However, no case of exercise induced asthma or asthma attack after exercise was found.

In order to investigate a difference between means of two sub-populations (e.g. asthmatics and non-asthmatics) which are related to each other such as FEV_1 and FVC before and after exercise, the t-test was applied to the data with conditions that variables must be continuous or quantitative, and that they are normally distributed. The test of normality was conducted and it was found that the data are normally distributed. The paired sample t-test showed that only FVC of non-asthmatics was significantly different (significant value is .015); FVC after exercise was higher than FVC before exercise in this group. For the independent samples t-test, there were no statistically significant differences of variance and mean for peak flow, FEV_1, FVC, and % change of FEV_1 and FVC.

Table 4.19 Summary of statistics of lung function test results among non-asthmatic children

Non-asthmatics

Parameter	N	Range	Min	Max	Mean	Standard error mean	Median
Age (year)	26	6	6	12	9.8	0.4	10
Weight (kg)	26	55	16	71	34.8	2.6	35
Height (cm)	26	46	112	158	138.5	2.5	139
PEF (L/min)	26	260	140	400	265.8	13.0	270
FEV_1 before exercise	26	1.88	0.97	2.85	1.76	0.11	1.65
FEV_1 after exercise	26	1.90	0.95	2.85	1.78	0.11	1.68
FVC before exercise	26	2.01	1.09	3.10	1.93	0.11	1.79
FVC after exercise	26	2.13	1.11	3.24	1.98	0.11	1.89
% change FEV_1	26	21	-8	13	1.58	0.86	3.00
% change FVC	26	21	-9	12	2.96	0.93	3.00
% FEV_1/FVC (pre)	26	17	80	97	91.00	0.83	92
% FEV_1/FVC (post)	26	17	81	98	90.00	0.84	89.5

Note: No. of non-asthmatic males = 13; no. of non-asthmatic females = 13.

Table 4.20 Summary of statistics of lung function test results among asthmatic children

Asthmatics

Parameter	N	Range	Min	Max	Mean	Standard error mean	Median
Age (year)	20	6	6	12	9.4	0.4	10
Weight (kg)	20	55	16	71	33.6	3.1	29.5
Height (cm)	20	52	110	162	135.7	2.9	135
PEF (L/min)	20	210	140	350	258	13.6	255
FEV_1 before exercise	20	1.55	0.71	2.26	1.60	0.09	1.59
FEV_1 after exercise	20	1.57	0.71	2.28	1.59	0.09	1.58
FVC before exercise	20	1.72	0.85	2.57	1.82	0.09	1.82
FVC after exercise	20	1.87	0.82	2.69	1.84	0.10	1.81
% change FEV_1	20	19	-9	10	-0.55	1.18	0.00
% change FVC	20	15	-7	8	0.70	0.97	1.00
% FEV_1/FVC (pre)	20	23	72	95	87.75	1.26	88
% FEV_1/FVC (post)	20	24	71	95	86.85	1.57	89.5

Note: No. of asthmatic males = 14; no. of asthmatic females = 6.

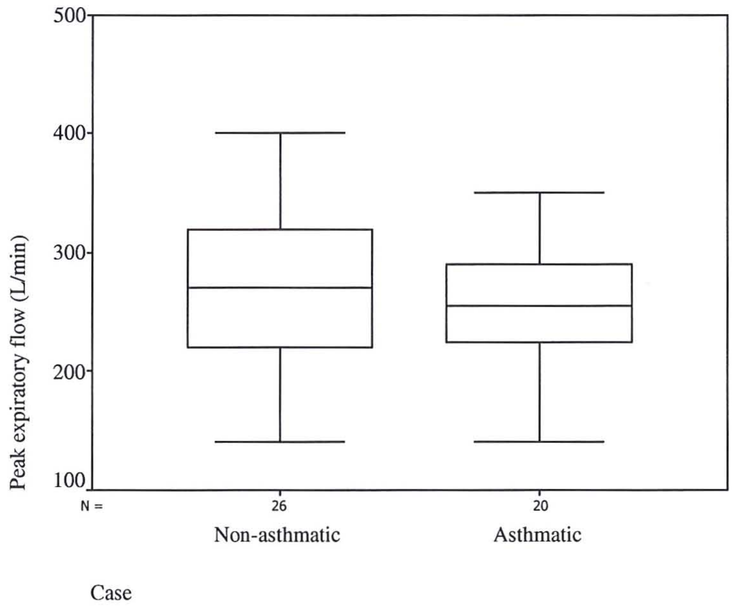


Figure 4.10 Box plot showing peak expiratory flow (PEF) in the non-asthmatic and asthmatic groups

4.4 Discussion

The frequency of current wheezing correlated with bronchial hyperresponsiveness is used to estimate the prevalence of asthma in northern Thai children in Chiang Mai (Trakultivakorn, 1999). The asthma prevalence found in this study is similar to that reported in a study by Trakultivakorn (1999) who examined children aged 6-7 years. In the past 12 months, exercise-related wheezing was reported by 4.1% of parents (Table 4.6), but the results of the present lung function tests conducted in asthmatic children suggest that exercise-induced asthma is not common. This is consistent with the observation that exercise-induced wheezing is not a prominent feature of childhood asthma in Southeast Asia (Vichyanond *et al.*, 1998). However, 11% of all children in this study gave reported night cough, which was also a common complaint in the ISAAC studies in Bangkok and Chiang Mai conducted by Vichyanond *et al.* (1998) and Trakultivakorn (1999), respectively. The most common symptom reported in this study was rhinitis symptoms. The prevalence of rhinitis in the past 12 months in Chiang Mai was 21.5% (Table 4.9) which is higher than that reported in the study of Trakultivakorn (1999) (18.5% in 6-7 year old children). From the questionnaire, the term 'hay fever' was translated into Thai as 'allergic to air' because there is no specific Thai term for hay fever (Trakultivakorn, 1999). The percentage of children (20.2%) with reported hay fever in this study was close to that found for current rhinitis (21.5%) (Table 4.6). About 31% of children suffering from rhinitis in the past 12 months had symptoms which interfered with their daily activities. A unique feature of rhinitis symptoms in children in Chiang Mai is its seasonal variation with peak incidence in October and November (Figure 4.11). The peak of seasonal allergic rhinitis (hay fever) was found between August to November in Trakultivakorn (1999), unlike the study of Vichyanond *et al.* (1998) in which the perennial nature (no seasonal variation) of rhinitis symptoms was observed among Bangkok children. For eczema, rash at the flexural areas is a typical manifestation of atopic dermatitis (Trakultivakorn, 1999). The prevalence of atopic dermatitis among all subjects aged 6 – 12 years in this study was approximately 11% (Table 4.9) which was slightly lower than the 13% of children aged 6-7 years reported in the study of Trakultivakorn (1999).

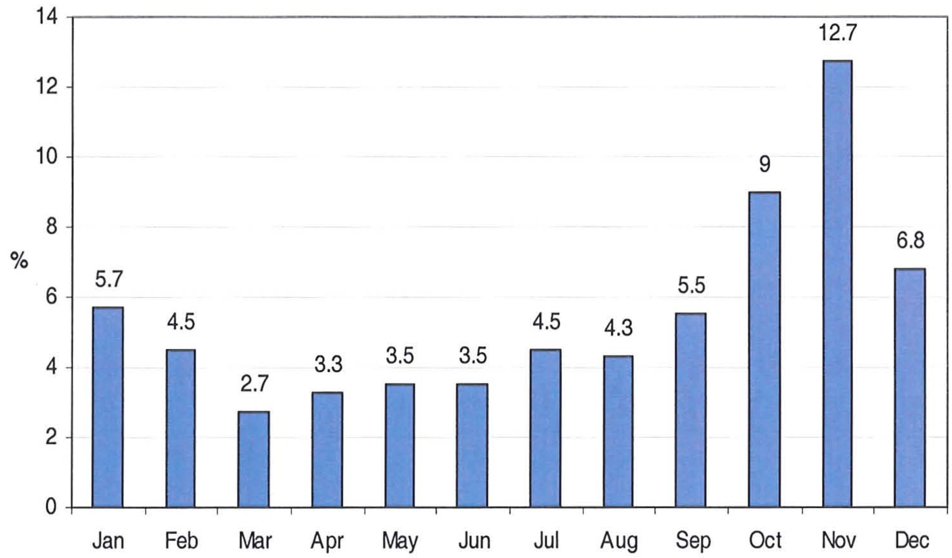


Figure 4.11 Percentage of children suffering from seasonal allergic rhinitis (hay fever) by month (n = 103).

Asthma, hay fever and eczema are atopic diseases with allergic conditions that tend to occur in families. They are associated with the production of abnormal amounts of specific immunoglobulin E (IgE) antibodies to common environmental allergens such as dust mites and pollen. The production of IgE is genetically controlled. A positive family for atopy and asthma in first-degree relatives is associated with sensitization to aeroallergens (Wahn and von Mutius, 2001). In this study, the association between asthma ('wheeze ever' and 'wheeze in the past 12 months' variables) and any of the potential environmental factors was not found, using logistic regression. This may due to the lack of important data, such as dust mites and pollen exposure, and family history (atopic diseases in the parents). Questions about these factors were not included in the ISAAC questionnaire.

The results of the logistic regression analysis showed that other diseases/symptoms (e.g. rhinitis, eczema, and atopic dermatitis) were associated with different environmental variables. In this study, trucks frequently passing home areas was identified as one of potential environmental factors associated with rash, eczema, and atopic dermatitis. This is in agreement with the finding of Montnemery *et al.* (2003) who investigated the prevalence of self-reported eczema in relation to the living environment in Sweden, and Schäfer and Ring (1997) who investigated the influence of air pollution on the prevalence of atopic eczema among German school children. They reported a higher prevalence of eczema among children living near roads with heavy traffic. It is plausible that diesel exhausts act as irritants leading to elevated IgE serum levels (Takafuji *et al.*, 1989). The diesel exhaust particles also enhance nasal cytokine secretion in humans (Diaz-Sanchez, 1997; Diaz-Sanchez *et al.*, 1996). Moreover, exposure to traffic, especially diesel exhaust, may exacerbate pre-existing allergic conditions, but does not necessarily induce the development of new cases of allergies (GINA, 2002).

It was found that the urban school locations were correlated with hay fever (OR 1.71, 95% CI 1.01-2.90, p = 0.046), rhinitis in the past 12 months (OR 1.58, 95% CI 0.95–2.63, p = 0.078) and atopic dermatitis (OR 1.97, 95% CI 0.93–4.19, p = 0.079). Children in the urban schools may be more exposed to urban air pollution that caused a higher prevalence of hay fever, rhinitis in the past 12 months and atopic dermatitis (see Table 4.7).

In this study, the birth weight variable was inversely associated with skin rash symptoms, although the associations were only marginally significant (rash ever OR 0.63, 95% CI 0.38–1.05, p = 0.075; rash in the past 12 months OR 0.60, 95% CI 0.34–1.06, p = 0.078; atopic dermatitis OR 0.58, 95% CI 0.31–1.06, p = 0.077). The average birth weight among the subjects was 3kg, which is normal for Thai infants (Table 4.4). Birth weights below 2.5kg are considered abnormal (e.g. prematurely-born infants, those that have HIV infections, or have nutritional deficiencies) (Tienboon and Wahlqvist, 1996). There were 45 out of 470 children (9.6%) whose birth weights were lower than 2,500g. However, a recent study of the risk factors for atopic dermatitis in New Zealand children, aged 3-5 years, (Purvis *et al.*, 2005) found that the prevalence of atopic dermatitis did not differ by birth weight, but was strongly associated with atopic disease in the parents. Low birth weight may cause a more significant health impact on respiratory functions than on skin allergies. Mortimer *et al.* (2000) studied the susceptibility to summer ozone among an asthmatic cohort – 846 inner-city asthmatic children aged 4-9 years. The children who had either low birth weight or a premature birth showed a greater response to ozone than the full-term infants or those with normal birth weights [i.e. PEF change (1.8% vs. 0.3% per 15 ppb ozone, $p < 0.05$); morning symptoms OR 1.42 vs. OR 1.09 per 15 ppb ozone, p < 0.05)].

The present study indicated that breastfeeding history was not associated with any of the atopic diseases in Chiang Mai, where most children (approximately 82%) were breastfed. Breastfeeding is normal practice among Thai mothers – particularly those on low incomes. In contrast, Purvis *et al.* (2005) found that there was a higher risk of atopic dermatitis with longer duration of breastfeeding: (<6 months, adjusted OR 6.13, 95% CI 1.45–25.86; ≥6 months, adjusted OR 9.70, 95% CI 2.47–38.15) compared with those never breastfed. This study suggested that breastfeeding should not be recommended for the prevention of atopic dermatitis. Sicklick (2005) commented that the role of breastfeeding in the prevention of asthma and allergies was unclear. The studies since the 1980s provided conflicting information whether breastfeeding was more likely or less likely to protect infants from developing these conditions. However, breastfeeding offers many health benefits for children and most experts strongly urge mothers to feed their infants exclusively for at least the first six months of life.

Antibiotics taken in the first year of a child's life were found to be related to rash and eczema, including atopic dermatitis. The use of antibiotics in early childhood has been suggested to be protective with respect to the development of asthma and allergy, because it may skew the balance between T-cell subpopulations from (normal) Th1-cell responses towards (atopic) Th2-cell responses, with increased production of IgE antibodies (Romagnani, 1992). However, a diminished Th1 immune response in early life may be a characteristic of an inherited predisposition to allergic diseases. It can be concluded that early childhood use of antibiotics is associated with an increased risk of developing asthma and allergic disorders in children who are predisposed to atopic immune responses (Droste *et al.*, 2000). In addition, high rates of antibiotic use may cause antibiotic resistance among children in Thailand. Many Thai doctors who normally prescribe antibiotics to children unnecessarily, may not be aware of the negative impacts of the excess use of these drugs on health. Visitsunthorn *et al.* (1995) reported that the use of antibiotics among 128 cases of asthmatic children admitted at Siriraj Hospital, Bangkok, decreased from 92% in 1982 to 80% in 1992. The children with asthma symptoms may have received antibiotics on the presumption that they had a bacterial respiratory infection. Furthermore, this PhD research showed that rhinitis and hay fever were significantly associated with paracetamol currently taken. This is because Thai children are normally given paracetamol when they have slight to serious symptoms of cold, rhinitis and hay fever. This is in part because paracetamol is widely available and inexpensive. Newson *et al.* (2000) also reported a correlation between paracetamol use and the prevalence of atopic diseases in children.

Food allergens have an important role in the development of skin allergies, especially atopic dermatitis. Burks (2003) reported that more than 90% of children with atopic dermatitis are allergic to food allergens derived from egg, wheat, milk, soy, and peanut. Children with food allergies normally immediately respond to a skin test because of increased IgE levels produced in direct response to these food allergens. In this study, nuts were associated with skin rash in the past 12 months (p = 0.013), rash ever (p = 0.016), eczema (p = 0.036), and atopic dermatitis (p = 0.080). Most of the children outgrow their allergies to milk, egg, wheat and soy, but their allergic reactivity to peanuts and tree nuts as well as to fish becomes manifest and is rarely resolved in adulthood (Burks, 2003). In this study, having contact with cats during the first year of life was one of the significant risk factors for atopic dermatitis, and having dogs in early childhood was related to rash and eczema. The results agree with those of other studies, which concluded that exposure to these pets during infancy may increase the risk of subsequent allergy to these animals (Popp *et al.*, 1990; Lindfors *et al.*, 1999). Where both parents were atopic, having cats at 12 months of age gave a huge risk for the development of sensitization to cats, but there was a much lower risk in the same age group in children whose both parents were non-atopic (Custovic *et al.*, 2001). Melen *et al.* (2001) found that, in comparison to unexposed children, children exposed to cats during the first two years of life were more likely to develop sensitization to cats by 4 years of age. High levels of cat allergen (Fel d1>8 μ/g dust) were associated with an increased risk of sensitization to cats. In contrast, other studies supporting the 'hygiene hypothesis' suggested that having a cat in the house during early childhood could later decrease the risk of sensitization to cats (Hesselmar *et al.*, 1999; Roost *et al.*, 1999). This hypothesis postulated an inverse relation between the incidence of infectious diseases in early life and the subsequent development of allergies and asthma (Martinez, 2001). This protective effect could be explained by the increased immunity of children exposed to cat allergen, due to a development of an optimal balance between Th2 to Th1-like immune responses in children (Custovic *et al.*, 2001). Ownby *et al.* (2002) found that exposure to 2 or more dogs or cats in the first year of life was associated with a lower prevalence of allergic sensitization (to multiple allergens) at age 6 to 7 years, regardless of exposure to dogs and cats at 6 years of age. In this study, having cats in the past 12 months was significantly correlated with the prevalence of eczema among school children in Chiang Mai. This may be because cat allergen triggers the underlying skin allergic disorders. However, a genetic component plays an important role in the expression of allergy. Some studies suggested that children who grew up on farms had significant protection against the development of atopy, and allergic rhinitis, and to a lesser extent, asthma (Ernst and Cormier, 2000; Riedler *et al.*, 2000 and von Ehrenstein *et al.*, 2000). Explained by Martinez (2001), high levels of endotoxin produced by farm animals (e.g. animal wastes) could play a role in the prevention of allergies. However, this is not the case in Chiang Mai where contact with farm animals by the child's mother is one of the significant risk factors for rhinitis and hay fever. Bolte *et al.* (2003) investigated the incidence of atopic sensitization, atopic dermatitis and wheezing of children, from age of 3 months to 2 years, exposed to different levels of endotoxin in mattress dust. The endotoxin increased the risk of atopic reactions to aeroallergens at the age of 2 years, especially in infants at risk due to parental atopy. Their results also disagree with an early protective effect of endotoxin on atopy development. However, there is a lack of data on the effect of endotoxin from prenatal stage. In the same context with cat allergen, endotoxin may be a risk factor in subjects who have already developed allergic diseases (Martinez, 2001). In this study, in Chiang Mai, child contact with farm animals was not correlated with any of the allergic diseases. This correlation may be seen if the children, who have resided since they were born in the farm environment particularly in rural areas of Chiang Mai, were included in the health survey. The farmers particularly those who own cattle normally reside in rural areas, not urban or suburban. In addition, the question about the child's contact with farm animals was only for the first year of child's life, which may be too short to obtain a protective effect of endotoxin in the farm environment. Moreover, Purvis *et al.* (2005) did not find the association between the atopic dermatitis and older siblings (implicated by the hygiene hypothesis). This is in an agreement with the study in Chiang Mai, where 36% and 8.3% of the child subjects had one and more than one older siblings, respectively. Controversially, Kilpelainen *et al.* (2000) found an inverse association between the number of older siblings and the occurrence of allergic rhinitis [with one older sibling (OR 0.86, 95 CI 0.77–0.96, $p<0.01$) and at least four older siblings (OR 0.47, 95% CI 0.26–0.84, $p<0.05$)]. The number of older siblings may have a stronger correlation to respiratory allergic symptoms than to skin allergies.

Maternal cigarette smoking is significantly associated with rash and eczema in this study. Until recently, there has been a lack of research on the impact of environmental tobacco smoke (ETS) on eczema and atopic dermatitis in children especially in the prenatal stage, although many studies mainly focus on wheezing and asthma, and some on rhinitis. A recent study in Germany among 1669 school beginners found that children were at a higher risk of developing an atopic eczema when exposed to ETS, especially children whose parents were atopic and had a higher risk of developing a sensitization against house dust mites (Kramer *et al.*, 2004). This German research could support the results of this Chiang Mai study although the subjects were not in the prenatal stage. Another German study, that found an adjuvant effect of ETS on allergic sensitization, was conducted by Kulig *et al.* (1999). The effect of pre- and postnatal tobacco smoke exposure on specific sensitization to food allergens and inhaled allergens was assessed in children during the first three years of life. The subjects were grouped into *utero* and postnatal ETS exposure. At the age of three, the children who were ETS exposed pre-and postnatally had a significantly higher risk of sensitization to food allergens than unexposed children. Although logistical analysis for asthma symptoms was not able to be conducted, it is recommended that maternal smoking should be avoided in any case because smoking during pregnancy is significantly associated with both reduced respiratory function and recurrent wheezing in infancy and early childhood and with the risk of development of IgE responses to food proteins early in life (Wahn and von Mutius, 2001).

In this study, other environmental variables were not able to be correlated with the diseases, such as the use of air conditioner/fan, fuel used for cooking, mother's education level and numbers of younger/older siblings. This may be because most of the school children used electric fans (86.5%) and only 0.6% used air-conditioners. Chiang Mai people normally use the fans with open windows for better air circulation. This normal practice may also reduce the levels indoor air pollution produced by fuels for cooking in open kitchens [LPG gas (57%) and/or open fires (15%)]. For children with respiratory and allergic diseases, genetic and air pollution factors play more important roles than the highest education levels of child's mother – mostly primary (68.9%) and secondary (22.5%).

Generally the validity or reliability of data collected from self-reporting such as questionnaire surveys is dependent upon people's memories. Some parents who have children suffering from allergies may have spent more time thinking of, for example, the causes of allergies and the months when the symptoms occurred, than the parents whose children are healthy. This is known as recall bias (Stewart, 2002). The ISAAC questionnaire was useful for this study and most questions are easy to comprehend. However, it has some limitations for application in Chiang Mai. For example, the ISAAC questionnaire was translated from an English version that has been used in Europe, Australia and New Zealand, and some food factors, which are not common in the northern Thai diet such as butter, margarine, pasta, potatoes and fast food should be excluded from the Thai version of ISAAC questionnaire. This is because they are not eaten for main meals in Thailand as in western countries. In addition, it may be difficult for the parents to reply about wheezing or hay fever symptoms. An explanation of the terminology of the diseases should be attached with the questionnaire. To overcome the limitations in this study, the children were interviewed to confirm the answers given in the questionnaire. This was to prove useful because some parents were found to have given incorrect answers particularly to questions relating to wheezing. For example, some parents whose children snored during sleeping misunderstood this and reported that their children had wheezed.

4.5 Conclusion

The application of the ISAAC questionnaire has proved useful for the study of respiratory diseases and allergies among school children in Chiang Mai, although again it has some limitations. The personal interview with the children and/or telephone interview with the parents were useful in order to obtain correct answers particularly about the respiratory and allergic diseases. Rhinitis, hay fever and atopic dermatitis are more common among children in urban areas than suburban areas. However, living in suburban areas does not appear to influence the occurrence of asthma – where genetic predisposition plays an important role. The logistic regression analysis of the reported data about the prevalence of respiratory and skin allergies, and environmental factors provides useful findings. The potential environmental factors that are significantly correlated with the allergic disorders among Chiang Mai children include diesel engine vehicles; the use of antibiotics and paracetamol; nuts; having contact with dogs and cats in the first year of life; having contacts with farm animals by mothers while pregnant; and maternal cigarette smoking. The findings are in disagreement with the hygiene hypothesis focusing on the protective effects of early exposure of farm animals and furred pets in early childhood. As far as the development of allergic sensitization and asthma in early childhood is concerned, maternal smoking and exposure to environmental tobacco smoke (ETS) seem to be important and such exposures should be avoided. The findings of this study will be used to help formulate recommendations in that part of this thesis concerned with sustainable measures for Local Air Quality Management (LAQM) in Chiang Mai.

CHAPTER 5

URBAN AIR QUALITY MANAGEMENT

5.1 Introduction

The fourth objective of this PhD programme is to compare current Air Quality Management (AQM) approaches in Thailand/Chiang Mai with those employed in Hong Kong Special Administrative Region (HK SAR) (see Sections 1.2 and 1.3). Specifically, the AQM system employed by the Hong Kong Environmental Protection Department (EPD) was compared with that conducted by the Thai Pollution Control Department (PCD). These two organizations have similar environmental management roles including AQM at a national level (the AQM responsibilities of Thai PCD are summarized in Section 1.5.2). The AQM systems of HK SAR and Thailand were compared based upon the principles of Good Urban Governance (GUG), a concept explained in Section 5.1.1.

The main criterion for selecting HK EPD included its advanced AQM system in Asia and this is recognized by Thai PCD; both government organizations being members of the Clean Air Initiative for Asian Cities (CAI-Asia) (pers. comm. Mr. Panya Warapetcharayut, Pollution Control Department). CAI-Asia was established in 2001 as an initiative of the Asian Development Bank (ADB), the World Bank (WB) and the United States Asia Environmental Partnership (US AEP), in order to promote and demonstrate innovative ways to improve the air quality of Asian cities through partnerships and shared experiences (CAI-Asia, 2005). During 2002-2004, CAI-Asia and the Air Pollution in Megacities of Asia (APMA) project conducted a benchmark study to evaluate AQM capability in 23 Asian cites in 5 stages. A rating, on a scale from Stage 1 (minimal capacity) to Stage 5 (excellent capacity), was assigned to each city. HK SAR was rated as having an 'excellent capacity' (Stage 5) in air quality management development, whereas Bangkok, Thailand was rated 'mature capacity' (Stage 4) (see Table 5.1) (Huizenga *et al.*, 2004). However, Chiang Mai City was not included in this study as it may not be large enough, in terms of population, to qualify as a major city.

Other criteria for selecting Hong Kong SAR included its location in the Asian continent, sub-tropical weather conditions, mountainous topography and its major air pollutants (particularly PM_{10} and O_3 which are similar to Chiang Mai).

Table 5.1 Stages of air quality management development in 23 Asian cities as part of a study on Benchmarking Urban Air Quality Management for Asian Cities, conducted by the Clean Air Initiative in Asian Cities (CAI-Asia)

Stage	Cities
STAGE 5 – Excellent Capacity Air quality management (AQM) is a routine activity. Well-established indigenous institutional capacity exists. Air quality levels are typically stable and below World Health Organization (WHO) guideline values as well as the national ambient air quality standards. Comprehensive control strategies are in place with a strong emphasis on air pollution prevention. Air quality standards and emission standards enforced on a regular basis.	Hong Kong, Osaka, Seoul, Singapore, Tokyo, Taipei
STAGE 4 – Mature Capacity AQM is increasingly comprehensive and well structured. External donor involvement limited to specialised areas. Regular AQM activities funded from local resources. Continuous air quality monitoring. Air quality levels improving and approaching WHO guideline values as well as national ambient air quality standards. Emphasis on development of medium-term strategies for key sources of pollution. Emerging emphasis on prevention of pollution. Enforcement of standards is becoming standard practice.	Bangkok, Beijing, Busan, New Delhi, Shanghai
STAGE 3 – Evolving Capacity A systematic approach to AQM is being implemented often with extensive external donor support. Air quality monitoring increasingly through continuous monitoring. Sustainability of institutional capacity not ensured from local resources. Air pollution levels high but stable. A reduction in pollutant levels for certain pollutants as a consequence of pollution control measures. A more structured approach to enforcement is emerging.	Ho Chi Minh, Jakarta, Kathmandu, Kolkata, Manila, Mumbai
STAGE 2 – Basic Capacity Initial legislation, standards and control measures exist. Air quality regulators heavily dependent on external donor support and local specialised institutions. Air quality monitoring limited to few stations, often manual monitoring. Enforcement of air quality regulations often very weak.	Dhaka, Hanoi, Surabaya, Yogyakarta
STAGE 1 – Minimal Capacity Cities unable to establish basic AQM capacity. Rising pollution levels common. No comprehensive air quality legislation and standards in place. Limited and *ad hoc* approach to air quality monitoring and pollution control.	Colombo, Karachi

Source: Huizenga *et al.*, 2004

5.1.1 Concept of Good Urban Governance

'Governance' was defined by the United Nations Development Programme (UNDP) (1997) as follows:

> *"The exercise of political, economic and administrative authority in the management of a country's affairs at all levels. It comprises the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights meet their obligations and mediate their differences."*

The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) simplified the meaning of governance to the process of decision-making and the process by which decisions are (or are not) implemented. Government itself is just one of the actors in governance. Depending upon the level of government (e.g. national, local), examples of other actors may include NGOs, research institutes, co-operatives, religious leaders, political parties, finance institutions and the civil society. Good governance consists of 8 major characteristics as follows: participation; rule of law; transparency; responsiveness; consensus oriented; equity and inclusiveness; effectiveness and efficiency; accountability (Table 5.2). As a set of principles, it can be used in several contexts such as corporate governance, international governance, national governance and local governance (UNESCAP, 2002). A city with good urban governance is well-managed and inclusive [United Nations Human Settlements Programme (UN-HABITAT), 2002].

Table 5.2 Eight characteristics of good governance

	Good governance characteristics
Participation	Participation by both men and women is a key cornerstone of good governance. Participation can be either direct or through legitimate intermediate institutions or representatives. It is important to point out that representative democracy does not necessarily mean that the concerns of the most vulnerable in society are taken into consideration in decision making. Participation needs to be informed and organized. This means freedom of association and expression on the one hand, and an organized civil society on the other hand.
Rule of law	Good governance requires fair legal frameworks that are enforced impartially. It also requires full protection of human rights, particularly those of minorities. Impartial enforcement of laws requires an independent judiciary and an impartial and incorruptible police force.
Transparency	Transparency means that decisions taken and their implementation are performed in a manner that follows rules and regulations and that information is freely available and directly accessible to those who will be affected by such decisions. It also means that enough information is provided and that it is provided in easily understandable forms and through accessible media.
Responsiveness	Good governance requires that institutions and processes try to serve all stakeholders within a reasonable timeframe.
Consensus oriented	There are always several actors and as many view points in a given society. Good governance requires mediation of the different interests in society to reach a broad consensus on what is in the best interest of the whole community and how this can be achieved. It also requires a broad and long-term perspective on what is needed for sustainable human development and how to achieve the goals of such development. This can only result from an understanding of the historical, cultural and social contexts of a given society or community.
Equity and inclusiveness	A society's well-being depends on ensuring that all its members feel that they have a stake in it and do not feel excluded from the mainstream. This requires all groups, but particularly the most vulnerable, have opportunities to improve or maintain their well-being.
Effectiveness and efficiency	Good governance means that processes and institutions produce results that meet the needs of society while making the best use of resources at their disposal. The concept of efficiency in the context of good governance also covers the sustainable use of natural resources and the protection of the environment.
Accountability	Accountability is a key requirement of good governance. Not only governmental institutions but also the private sector and civil society organizations must be accountable to the public and to their institutional stakeholders. Who is accountable to whom varies depending on whether decisions or actions taken are internal or external to an organization or institution. In general an organization or an institution is accountable to those who will be affected by its decisions or actions. Accountability cannot be enforced without transparency and the rule of law.

Source: UNESCAP (2002)

UN-HABITAT (2002) described that:

> "*Urban governance is inextricably linked to the welfare of the citizenry. Good urban governance (GUG) must enable women and men to access the benefits of urban citizenship. GUG, based on the principle of urban citizenship, affirms that*

no man, woman or child can be denied access to the necessities of urban life, including adequate shelter, security of tenure, safe water, sanitation, a clean environment, health, education and nutrition, employment and public safety and mobility. Through GUG, citizens are provided with the platform which will allow them to use their talents to the full to improve their social and economic conditions."

GUG is, therefore, crucial for effectively managing urban environments. In this study, each characteristic of GUG, with respect to air quality management in HK SAR and Thailand, is analysed and discussed (see Section 5.6).

5.1.2 Methodology - Comparison of Good Urban Governance

A comparison of air quality management (AQM) between HK SAR and Thailand was made based upon the Good Urban Governance (GUG) concept as defined by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) (UNESCAP, 2002). Each GUG characteristic regarding AQM was critically analysed by using the information available from different sources (e.g. references, personal communications and the author's experience). Following the GUG characteristics in Table 5.2, the methodological criteria for assessment can be summarized as follows;

i) Participation – Both men and women involved in AQM at a national level. At a national level, numbers of male and female staff of HK EPD and Thai PCD were investigated.

ii) Rule of law – Whether AQM regulations are sound and are impartially enforced.

iii) Transparency – Decision making conducted following rules and regulations. Information regarding the decision making processes of government organizations was investigated as to whether they were accessible and comprehensible to the public.

iv) Responsiveness – Whether services to all stakeholders were delivered within a responsible timeframe.

v) Consensus oriented – Different interests of all stakeholders taken into consideration by the government. Education in aspects of AQM was considered in terms of sustainable human development, resulting in improvement of environmental quality.

vi) Equity and inclusiveness – Whether the well-being of all members of society (e.g. especially children and the poor) was taken into consideration for improving air quality.

vii) Effectiveness and efficiency – Whether AQM systems were established to meet the needs of society while maintaining sustainable use of natural resources and environmental protection.

viii) Accountability – 'There should be no place for corruption in cities' (UN-HABITAT, 2002). Transparency in the financial reports of development projects was considered.

At a local level, the urban governance situations in Chiang Mai were also examined and assessed for differences from Bangkok Metropolitan or national policies and regulations.

5.1.3 Management Capabilities Index – A Method for Assessing Air Quality Management

As mentioned above, APMA and CAI-Asia conducted a study on the *Benchmarking Urban Air Quality Management in the Cities* (Huizenga *et al.*, 2004). Its main objectives were to assess the status of air quality management (AQM) in 23 Asian cities and to provide a benchmark from which future AQM development can be assessed. A questionnaire survey methodology developed by the Monitoring and Assessment Research Centre (MARC), United Nations Environment Programme (UNEP) and World Health Organization (WHO) (MARC/UNEP/WHO, 1996) was applied to assess AQM capabilities. A set of four indices representing key AQM components (e.g. air quality policies, monitoring, emissions inventory) was applied (see Table 5.3). The questionnaire contained four parts corresponding to the 4 indices. Each question was allocated a score and total points for each component index was 25 (hence 100 for all four indices). The questionnaires were completed by selected city authorities in Asia (e.g. Bangkok, Beijing, Hong Kong, New Delhi, Singapore, Tokyo). The limitations experienced in the administration of this questionnaire survey included incomplete questionnaires, and lack of cooperation from some city agencies (Haq *et al.*, 2002). Clarification of some unclear or incomplete answers was made via email, telephone and/or meetings to obtain additional information.

Table 5.3 Indices representing key components of air quality management capabilities used in the APMA/CAI-Asia benchmark study.

Index	Assessment of air quality management components
1. Air quality measurement capacity	Ambient air monitoring conducted in a city including the accuracy, precision and representiveness of air monitoring data.
2. Data assessment and availability	Processing of air quality data to provide relevant information in decision-making. Access to air quality information and data through different media.
3. Emission estimates	An emissions inventory to determine whether the information on sources of air pollution in the city were available.
4. Management enabling capabilities	The AQM administrative and legislative framework through which emission control strategies were introduced and implemented.

Source: Huizenga *et al.*, 2004

5.1.4 General Information of Hong Kong SAR

Hong Kong SAR is located in the southeast of the People's Republic of China (PRC) in the Asian continent (Figure 5.1) and has a sub-tropical climate. The topography of HK SAR is similar to that of Chiang Mai, with hills and mountains dominating and some flat areas in the Kowloon peninsular and the northwestern New Territories. The total area of Hong Kong was originally 1,095 km^2. Land reclamation projects have expanded the land of HK SAR (Hong Kong Island, Kowloon peninsular, the New Territories and remote islands) by over 1,100 km^2. Agricultural areas are mainly in the alluvial plains of the New Territories. Land heights in Hong Kong range between 66m in Lo Chau Mun to 957m in Ta Mo Shan located in the central part of New Territories. In Hong Kong, monsoons and seasonal winds dominate the climate. The temperatures range from 10-20°C in winter (mid December-February) to 26-33°C in summer (June-mid September) (Mari Mari http://www.marimari.com/, 2004). With respect to air quality management, the Environmental Protection Department (EPD) is the responsible government agency for the control of both indoor and outdoor air pollution including: vehicle emission reduction; legislation; public consultation; distribution of air quality information. The author officially visited EPD during 8 – 12 November 2004 in order to gain a better understanding and experience of air quality management in HK. The information obtained is summarized and discussed below.

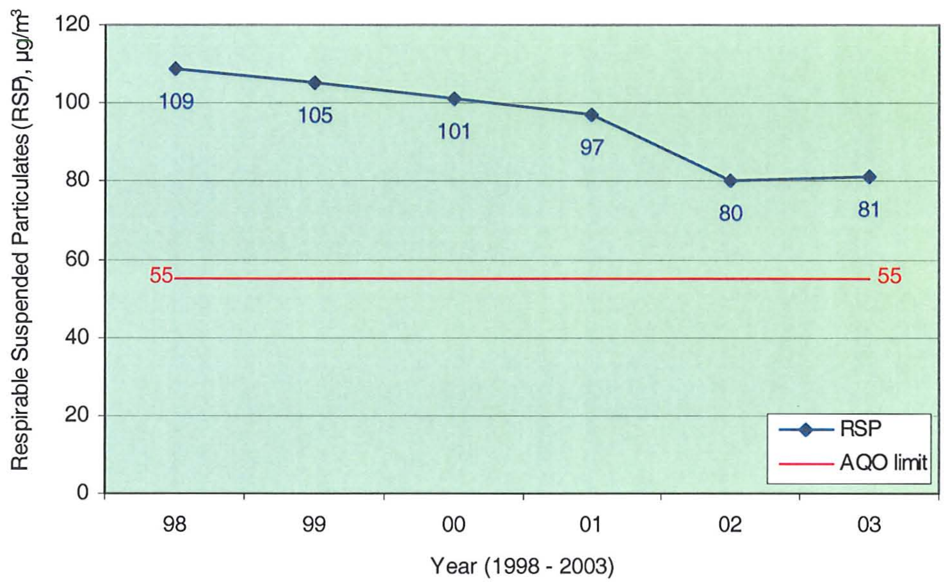
Modified from http://www.vectormap.com/eng/english.htm

Figure 5.1 Map of Hong Kong SAR showing the location of air monitoring stations.

5.2 Description of Air Pollution in Hong Kong SAR

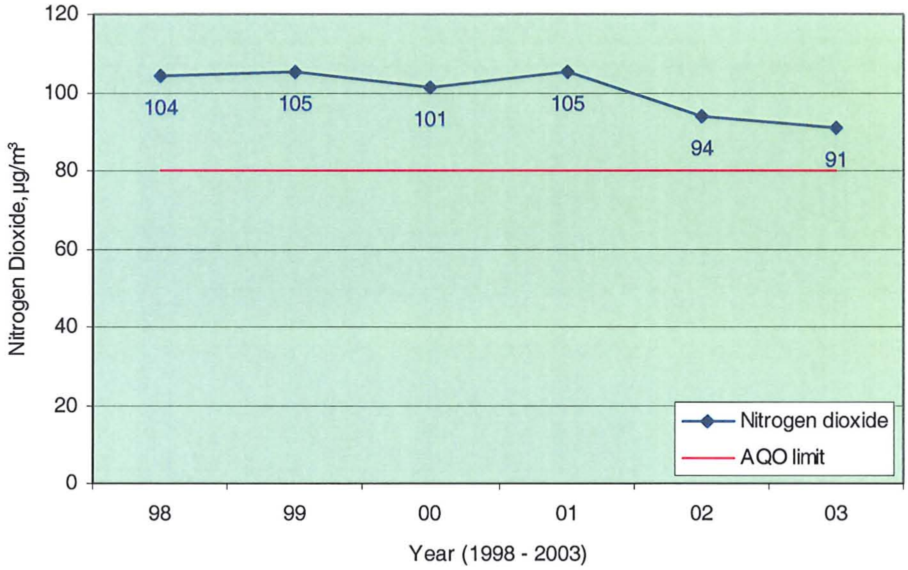
EPD summarises air quality monitoring data in published annual reports on Air Quality in Hong Kong. The main pollutants considered are total suspended particulates (TSP), respirable suspended particulates (RSP or PM_{10}) and nitrogen dioxide (NO_2) at roadside stations. The reports show that air quality has gradually improved since 2000 due to air pollution control measures in the previous years. However RSP and NO_2 concentrations remain higher than the Air Quality Objectives (AQO) at roadside stations. Trends for annual RSP, NO_2 and O_3 are illustrated in Figures 5.2 – 5.4. The air quality data for RSP and NO_2 as reported for the years 1998 – 2003 were collected at the Causeway Bay monitoring station (Figure 5.1) and the O_3 data were collected at the Tap Mun monitoring station (EPD, 1998-2003a). These clearly show that although RSP and NO_2 concentrations have decreased since 1998, O_3 concentrations are increasing. Other measured pollutants – sulphur dioxide (SO_2), carbon monoxide (CO) and lead (Pb) – were well below their AQO limits. For this Chapter, monitored air pollution concentrations at the Causeway Bay station were selected to represent the worst roadside air quality in HK SAR, particularly RSP (or PM_{10}) and NO_2 (Figures 5.2-5.3). Causeway Bay is one of the most crowded, commercial areas on Hong Kong Island. High rise buildings and traffic congestion are significant features (Figure 5.5). From the Air Quality Data in Hong Kong reports, between

1998 – 2003, the highest annual average concentrations of RSP and NO_2 were recorded at the Causeway Bay station on Kowloon every year, with the exception of the highest annual NO_2 concentrations in 2003, which were recorded at the Mong Kok station (EPD, 1998 – 2003a). Annual average O_3 data from a monitoring station on Tap Mun, a small island in the northeast of HK SAR, were considerably elevated above the standard (Figure 5.4). The highest annual average O_3 concentrations were found at this station every year between 1998-2003. Causeway Bay and Tap Mun air quality monitoring stations have operated since 1997. Graphs illustrating annual average RSP (or PM_{10}), NO_2 and O_3 in HK SAR as reported for the years 1998 – 2003 were produced by the author using data from EPD *Air Quality Data in Hong Kong* reports.



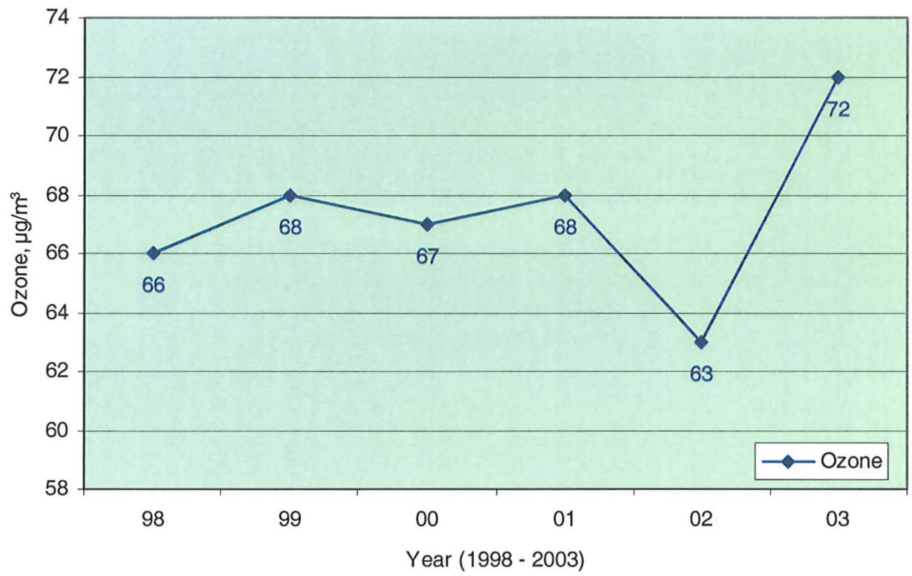
Source: EPD (1998-2003a)

Figure 5.2 Annual average respirable suspended particle (RSP or PM_{10}) concentrations as reported for the Causeway Bay monitoring station from the years 1998 to 2003.



Source: EPD (1998-2003a)

Figure 5.3 Annual average nitrogen dioxide (NO_2) concentrations as reported for the Causeway Bay monitoring station from the years 1998 to 2003.



Source: EPD (1998-2003a)

Figure 5.4 Annual average ozone (O_3) concentrations as reported for the Tap Mun monitoring station from the years 1998 to 2003.

.

Photographed by K. Sriyaraj

Figure 5.5 In front of the Sogo Department Store in Causeway Bay, where a roadside particulate monitoring unit is located.

A comparison of air quality data in HK SAR was made from 1998 – 2002 (the data are available until 2002 on the EPD website as of December 2004). In 1999, it was found that 296$\mu g/m^3$ was the highest recorded concentration of PM_{10} (24-hr average) in Central, HK Island. The highest recorded concentration of PM_{10} in 1 hour reached 555$\mu g/m^3$ at the Central monitoring station, while the Causeway Bay monitoring station detected the highest monthly concentrations in every year. The highest average monthly PM_{10} ever recorded at this station was 133$\mu g/m^3$ in May 1998.

In comparison to air quality data for Chiang Mai, annual average roadside PM_{10} or RSP concentrations in HK SAR were normally slightly higher than in Chiang Mai and exceptionally higher in 2001 (Figure 5.6). However, the comparison should be viewed with caution as it is noted that there is only one permanent roadside monitoring station in Chiang Mai and three in HK SAR, therefore, the comparison of PM_{10} concentrations was made between an annual PM_{10} average from all three roadside stations in HK SAR (i.e. Causeway Bay, Central, Mong Kok) and from one station in Chiang Mai (i.e. Yuparaj School) for each year. Concentrations of NO_2 in HK SAR were much higher than those in Chiang Mai during from 1998 – 2002, although annual average NO_2 concentrations in Chiang Mai increased by 100% from 1998 – 2002 (Figure 5.7). The comparison of O_3 between Chiang Mai and HK SAR was also made, based on air quality data (annual average) from only one permanent ambient monitoring station in Chiang Mai (Provincial Hall), and 11 ambient stations in HK SAR. However, for some years data were not available at one or two EPD monitoring stations. Figure 5.8 shows that the annual average O_3 concentrations in Chiang Mai were slightly higher than in HK SAR.

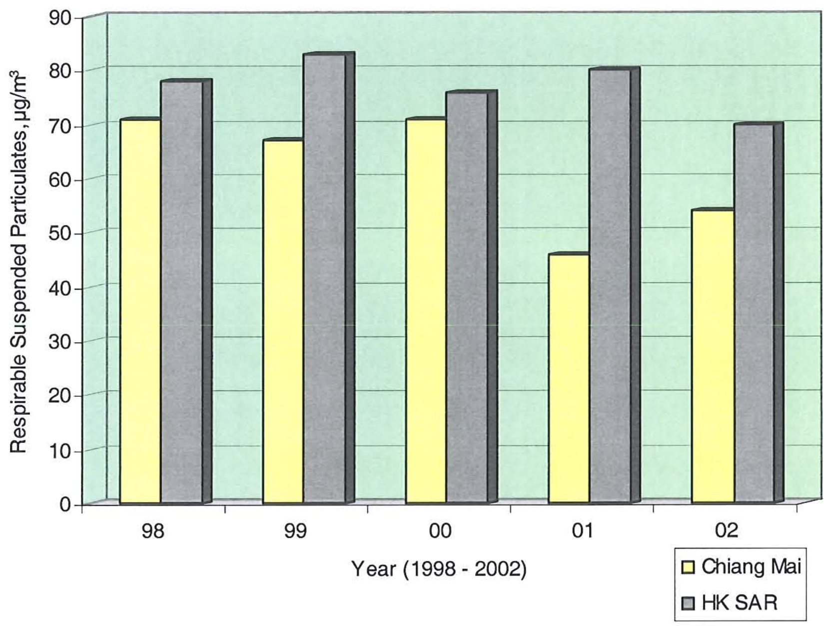


Figure 5.6 Comparison of annual average PM_{10} (or RSP) concentrations between Chiang Mai, Thailand and HK SAR, China. The data presented are for average concentrations recorded for 3 roadside stations in HK SAR (EPD, 1998-2003a) and for 1 roadside station in Chiang Mai (Thai PCD annual reports from 1999-2003 State and Management of Air and Noise Pollution).

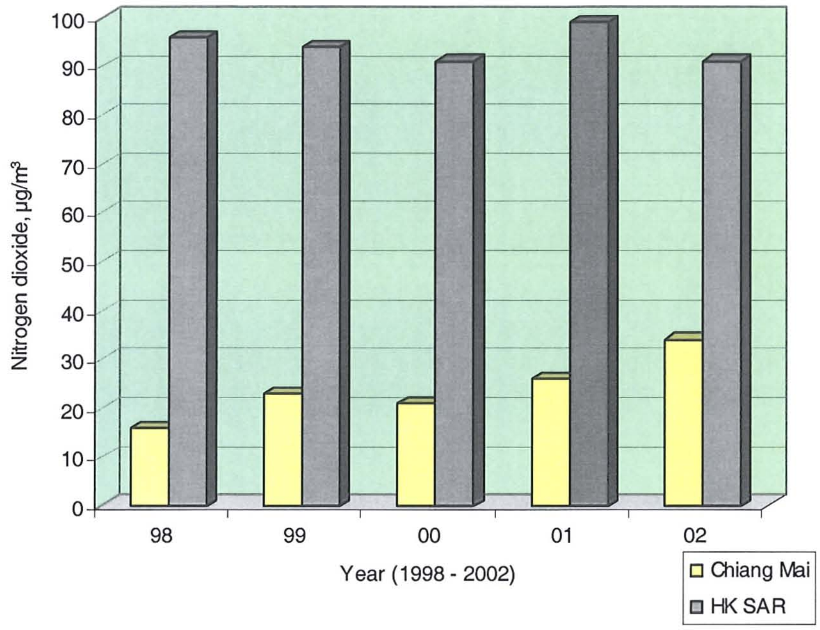


Figure 5.7 Comparison of annual average NO_2 concentrations between Chiang Mai, Thailand and HK SAR, China. The data presented are for average concentrations recorded for 3 roadside stations in HK SAR (EPD, 1998-2003a) and for 1 roadside station in Chiang Mai (Thai PCD annual reports from 1999-2003 State and Management of Air and Noise Pollution).

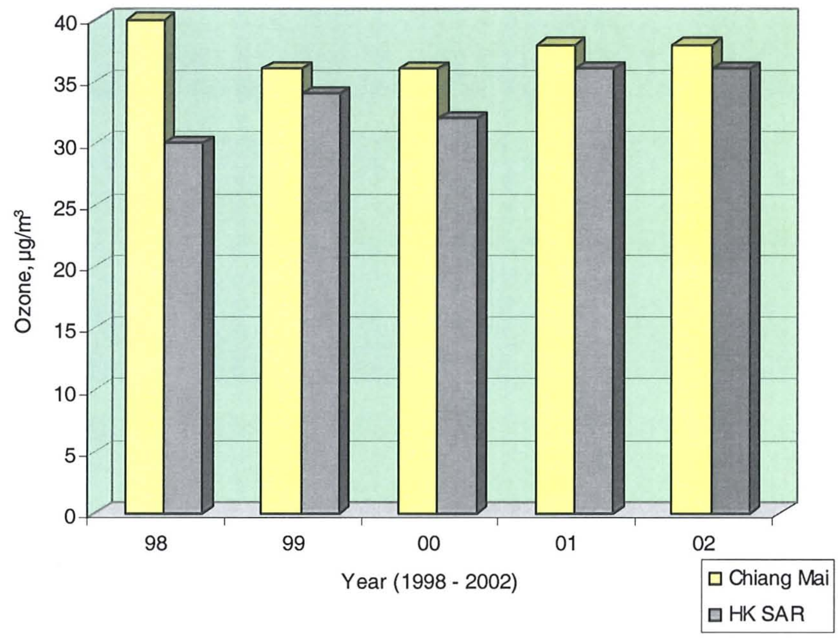


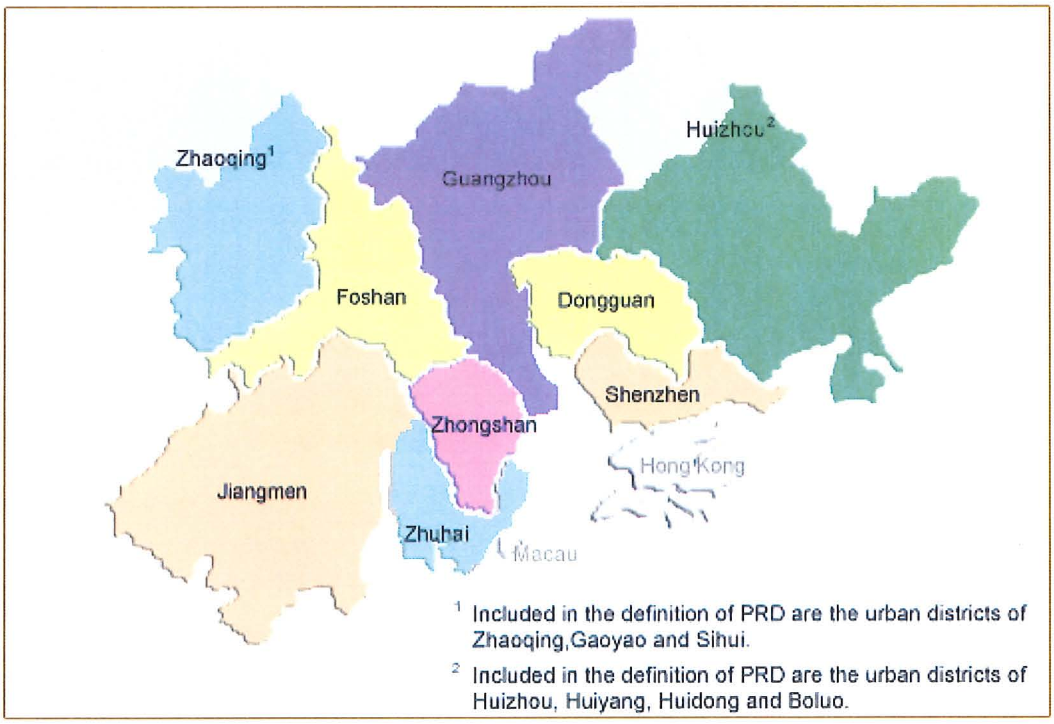
Figure 5.8 Comparison of annual average O_3 concentrations between Chiang Mai, Thailand and HK SAR, China. The data presented are for average concentrations recorded for 11 ambient stations in HK SAR (EPD, 1998-2003a) and for 1 ambient station in Chiang Mai (Thai PCD annual reports from 1999-2003 State and Management of Air and Noise Pollution).

5.3 Sources of Air Pollution in Hong Kong SAR

An example of serious air pollution in HK SAR is illustrated in Figure 5.9, which shows a typical hazy daytime view of Victoria Harbour. This visibility impairment occurs when particles, mostly particles less than 2.5 μm in diameter ($PM_{2.5}$), generated by anthropogenic activities, and gases in the atmosphere scatter and absorb light (le Clue, 2004). It should be noted that all annual $PM_{2.5}$ concentrations from the pilot study on the Use of Atmospheric Measurements to Manage Air Quality in Hong Kong and the Pearl River Delta (PRD): Fine Particulate Matter ($PM_{2.5}$) in the PRD were 2 to 5 times above the US National Ambient Air Quality Standards (US NAAQS) (15μg/m^3) (Bergin *et al.*, 2004). In addition, from the Study of Air Quality in the Pearl River Delta Region (hereafter referred to as 'the Joint Study'), major sources of air pollution, especially suspended particulate matter, in HK SAR include motor vehicles and the non-metallic mineral industry (e.g. cement and brick production) (CH_2M Hill Ltd., 2002). In addition to local sources, air polluting activities in the Pearl River Delta Economic Zone (PRDEZ) in Mainland China – an area comprising Guangzhou, Shenzhen, Zhuhai, Donguan, Zhongshan, Foshan, Jiangmen and part of Huizhou and Zhouqing – produce a significant proportion of PM_{10} in HK SAR (Figure 5.10). The Joint Study estimated that, in 1997, the PRDEZ produced 95% of PM_{10} production in the region while HK SAR contributed the remaining 5%. The annual regional background PM_{10} concentration in the region was about 40μg/m^3, which was considered high relative to both HK SAR and PRDEZ standards. Without any extra control measures, emissions of PM_{10} are expected to increase by 45% in the region, in comparison to a baseline year of 1997. The predicted major source of additional PM_{10} is power generation due to an increasing demand for electricity and the use of coal, instead of alternative cleaner fuels such as natural gas.

Photographed by K. Sriyaraj

Figure 5.9 Poor visibility across Victoria Harbour around noon, Sunday 7 November 2004



Source: http://www.teamone.com.hk/ prd_glance.php

Figure 5.10 Map illustrating provinces in Mainland China included in the Pearl River Delta Economic Zone (PRDEZ)

Major sources of air pollutants in HK SAR, as listed in the 2002 emissions inventory, are summarized in Table 5.4. As expected, motor vehicles produced significant proportions of the local emissions of PM_{10} (38%), NO_x (31%), CO (90%), and Pb (100%), while power generation mainly produced SO_2 (89%), PM_{10} (37%), NO_x (45%), and CO_2 (62%). Non-combustion sources such as paints and printing contributed a large proportion of VOCs (80%). In addition, the 'canyon effect' worsens air pollution at street level because air pollutants are trapped between extremely tall buildings. $PM_{2.5}$ is also another air pollutant of concern in HK SAR and PRDEZ. From the Hong Kong and Pearl River Delta Pilot Air Monitoring Project (2002 – 2004) (Civic Exchange, 2004), annual average $PM_{2.5}$ concentrations from monitoring stations in Guangzhou, Shenzhen, Zhongshan and Conghua in mainland China were 71, 47, 46 and 37μg/m^3 respectively. Whereas lower annual average $PM_{2.5}$ concentrations were found at Central & Western (34μg/m^3), Tung Chung (32μg/m^3), and Tap Mun (29μg/m^3) monitoring stations in HK SAR. Organic carbon and sulphate dominated fine particulate chemical species in the region accounting for 24 – 35% and 21 – 32% of $PM_{2.5}$ mass, respectively. At the Guangzhou site, the main sources of $PM_{2.5}$ were biomass burning and motor vehicles. High concentrations of potassium – a tracer of biomass burning, and lead from leaded gasoline were both found in the $PM_{2.5}$ and were used for source attribution (Civic Exchange, 2004). Whereas the main sources of $PM_{2.5}$ in HK SAR were vehicle exhaust and other combustion emissions such as cooking, industrial combustion and biomass burning – indicated by high organic and elemental carbon concentrations, determined by the mass analysis of the $PM_{2.5}$ (Louie *et al.*, 2005).

Table 5.4 Major local sources of air pollutants in HK SAR from 2002 emissions inventory

Pollutants	Major sources in 2002
SO_2	Power generation (89%); Marine vessels (5%); Fuel combustion (industrial/commercial/domestic) (5%)
PM_{10} or RSP	Vehicles (38%); Power generation (37%); Non-combustion (e.g. dust, construction) (15%); Marine vessels (6%)
NO_x	Power generation (45%); Vehicles (particularly diesel) (31%); Marine Vessels (16%); Aircraft (4%); Fuel combustion (industrial/commercial/domestic) (3%)
CO	Vehicles (90%)
O_3	See breakdowns of sources of two ozone precursors; NOx and VOCs
Pb	Vehicle (100%)
VOCs	Non-methane VOC: Non combustion (e.g. consumer products, paints, printing) (80%); Vehicles (18%)
CO_2	Power generation (62%); Vehicles (18%); Waste burning (12%)

Source: EPD

5.4 Health Impacts of Air Pollution in Hong Kong SAR

HK SAR was rated as one the most pollution-aware countries by the Health Effects Institute (HEI), an independent health-related research organization based in Boston, USA, in terms of the number of air pollution related health studies that it has published (HEI, 2004). The HEI identified 138 scientific papers, published from 1980 to mid 2003, that present estimates of health impacts of outdoor air pollution in Asia. Most studies were conducted in mainland China, Taipei, Hong Kong, South Korea and Japan. A few studies were conducted in South Asia (India) and Southeast Asia (e.g. Thailand, Malaysia, Singapore). Since 1997, EPD has commissioned studies on the health effects of exposure to air pollutants. Most studies were concerned with short-term health effects (i.e. daily hospital admissions and daily mortality) produced by cardio-respiratory diseases.

In 2002, EPD commissioned the University of Hong Kong to conduct a *Study of Short-term Impact and Costs due to Traffic-related Air Pollution*, in order to investigate the short-term effects of air pollution on morbidity and total mortality, and to assess direct and indirect costs. The costs that individuals were willing to pay to prevent the health effects of air pollution were also evaluated (Wong *et al.*, 2002). The findings showed that an increase of $10\mu g/m^3$ in the concentration of pollutants was associated with a 0.6–2.1% increase across all diseases categories for NO_2; 1.4–3.9% increase across all disease categories for SO_2; 0.2% increase in all non-accidental causes and 0.9% increase in chronic obstructive pulmonary disease for PM_{10}; 0.6% increase in respiratory disease for O_3. For hospital admissions (except for asthma), 4 pollutants (NO_2, SO_2, PM_{10}, and O_3), were associated with increased admissions across all the disease categories. For each additional $10\mu g/m^3$, there was a 0.5–1.9% increase for NO_2; 0.5–2.4% increase for SO_2; 0.4–1.0% increase for PM_{10}; 0.2–0.6% increase for O_3. Using the 1995–2000 database, the number of cardio-respiratory deaths that could be attributed to a $10\mu g/m^3$ change in concentration of each pollutant was 243 deaths a year (for SO_2) and, for the fraction due to traffic related air pollution was 83 deaths a year (for NO_2). For cardio-respiratory disease, SO_2 and NO_2 were estimated to have caused 1917 and 821 hospital admissions, respectively. In 2000, an annual estimate monetary value of air pollution effects on cardio-respiratory diseases in HK SAR, for total air pollution and for the fraction due to traffic-related air pollution, was HK$11.1 billion; and HK$6.9 billion respectively; and for direct cost of illness was HK$1.3 billion and HK$0.8 billion respectively (Wong *et al.*, 2002). These findings are being used by policy makers in HK SAR to assess the benefits that would be obtained by the implementation of clean air policies.

5.5 Hong Kong Environmental Protection Department – Its Roles and Environmental Legislation

Hong Kong EPD was established in 1986. It is responsible for: proposing policies; enforcing environmental legislation; monitoring environmental quality; providing collection, transfer, treatment and disposal facilities for many types of waste; advising on the environmental implications of town planning and new policies; handling pollution complaints and incidents; raising awareness and support in the community for environmental initiatives. Currently, EPD has seven action programmes concerned with: air; community relations; environmental assessment and planning; noise; waste; waste facilities; water. In the Air Programme, EPD focuses on air pollution control by developing objective air quality standards and guidelines; drafting and implementing programmes to control air pollution; enforcing the Air Pollution Control Ordinance (APCO) and Ozone Layer Protection Ordinance (OLPO) to control air pollution from different sources; scrutinising project development proposals and land use plans; operating an air quality monitoring network and laboratories; and providing air quality information to the public (The Government of HK SAR, 1997). In addition, EPD is empowered by the APCO to impose a licensing control on major stationary emission sources, namely the Specified Processes, which are major stationary air polluters such as power plants, incinerators and concrete batching plants, and issue legal notices to air pollution sources to demand remedial actions. EPD is also tasked to achieve defined Air Quality Objectives (AQOs) (Table 5.5) and to maintain the achieved air quality.

5.5.1 Air Pollution Control Legislation and Enforcement

The first air pollution control legislation in Hong Kong was the Clean Air Ordinance, enacted in 1959, for controlling emissions from fuel combustion. The Air Pollution Control Ordinance (APCO) was developed from the Clean Air Ordinance in order to extend the scope of control to cover non-combustion processes in 1983, and vehicle emissions in 1991. APCO was further amended to cover other air pollutants such as asbestos. In the Ordinance, a statutory framework was provided for establishing the Air Quality Objectives (AQOs) and stipulating control requirements for air pollution sources (EPD, 2004a). EPD can issue an Air Pollution Abatement Notice to the owner of a process or activity that is causing air pollution. The Notice requires the owner to take remedial action to either decrease or eliminate the emissions. For controlling emissions from any Specified Process, a 2-year licence is required for the operation of these processes. During the licence application stage, the application is required to be publicly notified in newspapers in both Chinese and English in order to inform all members of the public. Within 30 days from the date of public notification, members of the public can object to the granting of the licence on the grounds of either the non-attainment of AQOs or that granting such a licence would be prejudicial to health. Depending upon the fulfillment of the environmental standards, EPD may either grant or refuse to grant a licence to the applicant. Operation of any Specified Processes without a licence or contravening licence conditions is an offence. The maximum fines for convictions range from HK$100,000 to HK$500,000 and from 6 to 12 months imprisonment.

Table 5.5 Air quality objectives (AQO) of Hong Kong

Pollutant	**Concentration (μg/m³) for different averaging times[i]**					**Health effects of pollutant at elevated ambient levels**
	1-hr[ii]	**8-hr[iii]**	**24-hr[iii]**	**3-m[iv]**	**1-yr[iv]**	
Sulphur dioxide	800		350		80	Respiratory illness; reduced lung function; morbidity and mortality rates increase at higher levels.
Total Suspended Particulates (TSP)			260		80	Respirable fraction has effects on health.
Respirable Suspended Particulates (RSP) [v]			180		55	Respiratory illness; reduced lung function; cancer risk for certain particles; morbidity and mortality rates increase at higher levels.
Nitrogen dioxide	300		150		80	Respiratory irritation; increased susceptibility to respiratory infection; lung development impairment.
Carbon monoxide	30,000	10,000				Impairment of co-ordination; deleterious to pregnant women and those with heart and circulatory conditions.
Photochemical oxidants (as ozone) [vi]	240					Eye irritation; cough; reduced athletic performance; possible chromosome damage.
Lead				1.5		Affecting cell and body processes; likely neuro-psychological effects, particularly in children; likely effects on rates of incidence of heart attacks, strokes and hypertension.

Note: (i) Measured at 298K(25°C) and 101.325kPa (one atmosphere); (ii) Not to be exceeded more than three times per year; (iii) Not to be exceeded more than once per year; (iv) Arithmetic means; (v) Respirable suspended particulates means suspended particles in air with a nominal aerodynamic diameter of 10 micrometres or smaller; (vi) Photochemical oxidants are determined by measurement of ozone only
Source: EPD (2004a)

The HK SAR Government generally issues Technical Memoranda which include technical references such as principles, procedures, guidelines, standards and limits, for people who are running or intend to establish any factory or business that may pollute the environment. The Government may also issue Codes of Practice, which are general advice to encourage emission reduction and air pollution control. There are 13 subsidiary regulations in force under APCO that enable the regulations to be more specific and effective for specific air polluting sources such as: furnaces and chimneys; motor vehicles; Specified Processes; petrol stations; dry cleaning services; open burning (The Government of HK SAR, 1997). With respect to the broader implications of emission reduction for greenhouse gases, the Ozone Layer Protection Ordinance (OLPO) controls the refrigerants used in motor vehicles and large refrigeration equipment in order to prevent further damage to the ozone layer (EPD, 2005).

Moreover, air quality objectives (AQOs) were established in 1987 under APCO, based on international standards derived from scientific studies of the correlation between ambient pollutant concentrations and adverse human health effects (Table 5.2). In order to achieve the AQOs, several preventive measures, including the enforcement of APCO and its subsidiary legislation, are conducted at the planning stage onwards for any possible activities that could result in air pollution.

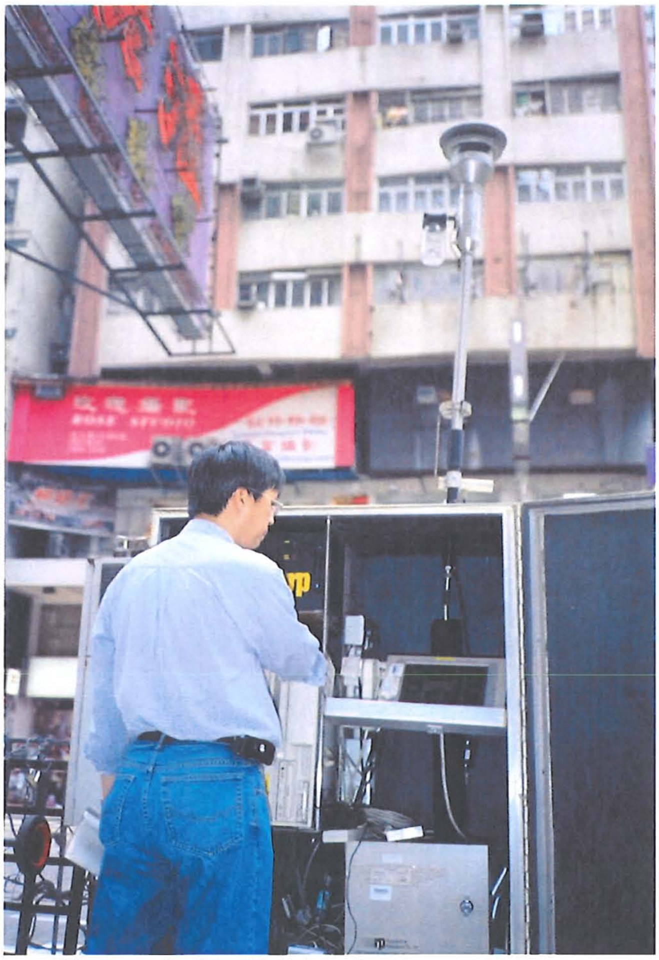
5.5.2 Air Quality Management

5.5.2.1 Monitoring and QA/QC

EPD has operated a network of air quality monitoring stations at different locations in HK SAR territory since 1983. At present, there are 14 monitoring stations (3 roadside and 11 ambient) in the monitoring network. The main objective of the stations is to provide information on ambient and roadside air pollution levels, under APCO, for managing air quality (EPD, 2002b). The information produced enables EPD to understand and estimate pollutant exposures to the population. Each monitoring station provides air quality data continuously. The Causeway Bay roadside station, which the author visited, is divided into 2 parts, a gaseous air quality monitoring unit and a roadside particulate monitoring unit. Due to the limited space available, the former unit is located on the 4th floor of the Sogo Department Store (Figure 5.11) and the latter, mainly for monitoring particulates, is located on the footpath in front of this store (Figure 5.12). At least one EPD staff member routinely visits each monitoring station in the network, for one or two days each week. In addition to monitoring, EPD pays particular attention to quality control (QC) and quality assurance (QA). QA staff are mostly based in the laboratory, but QC staff are responsible for the daily operation of the sampling network and for data processing. Each sampler is calibrated every three months. For single point gaseous analysers, a QC check on zero and span drifts for each analyzer is conducted daily. QA is undertaken as part of a performance audit on field measurements using independent calibrators and standards (e.g. NIST-SRM). The QA audits are conducted to a higher standard than those adopted for daily field operations (e.g. US-EPA protocol) (pers. comm., Mr. Gordon Leung).

Photographed by K. Sriyaraj

Figure 5.11 The Causeway Bay gaseous air quality monitoring unit



Photographed by K. Sriyaraj

Figure 5.12 The Causeway Bay roadside particulate monitoring unit

5.5.2.2 Air Pollution Index (API)

EPD has reported levels of air pollution to the public in the form of an Air Pollution Index (API) since June 1995. This index is used to provide information on air pollution levels in a simple way, assessable to the public. To produce the index, EPD converts concentrations of 5 main pollutants (namely, NO_2, SO_2, O_3, CO and RSP) relative to the relevant Air Quality Objectives (AQO) to a value on a scale of between 0–500 (EPD, 2006a). APIs for each pollutant are calculated and the highest API number of that hour is reported as the index. EPD also reports an API forecast for the following day. The purpose of this is to issue the public with an alert before the onset of serious air pollution episodes. This can be especially useful for susceptible individuals, such as those with heart or respiratory illnesses, who could consider taking precautionary measures to avoid exposure and subsequent problems.

API scores for Central, Mongkok and Causeway Bay are printed in some of the HK papers (e.g. South China Morning Post) and the ranges displayed with different colours. The API is divided into 5 bands according to the potential effects on health. An API higher than 100 means that one or more pollutants may have immediate health impacts to some susceptible members of the community. The potential health effects for each API range are summarized in Table 5.6 and the corresponding precautionary actions recommended by the EPD are summarized in Table 5.7.

Table 5.6 Air Pollution Index (API) ranges relating to air quality status, air pollution level and health implication

API	Air quality status	Air pollution level	Health implications*
201 to 500	Air quality significantly worse than both short-term and long-term AQOs.	Severe	People with existing heart or respiratory illnesses will experience significant aggravation of their symptoms and there will be also widespread symptoms in the healthy population. These include eye irritation, wheezing, coughing, phlegm and sore throat.
101 to 200	Air quality worse than both short-term and long-term AQOs.	Very high	People with existing heart or respiratory illnesses will notice mild aggravation of their health conditions. Generally healthy individuals may also notice some discomfort.
51 to 100	Air quality within the short-term AQOs but worse than the long-term.	high	Very few people, if any, may notice immediate health effects. Long-term effects may, however, be observed if you are exposed to such levels for a long time.
26 to 50	Air quality within all AQOs.	Medium	None expected for the general population.
0 to 25	Air quality well within all AQOs.	Low	None expected.

Note: * The health implications set out above serve as a broad guide only as a gradual increasing risk of effects is expected as pollutant concentrations rise. **Source:** EPD (2006a)

Table 5.7 Recommended precautionary actions, relating to Air Pollution Index (API)

API	Air pollution level	Advice to the public	
		General API	**Roadside API**
201 to 500	Severe	The general public is advised to reduce physical exertion and outdoor activities.	The general public is advised to avoid prolonged stay in areas with heavy traffic. If it is necessary to stay in streets or roads with heavy traffic, they are advised to reduce physical exertion as far as possible.
101 to 200	Very high	Persons with existing heart or respiratory illnesses (such as coronary heart and cardiovascular diseases, asthma, chronic bronchitis and chronic obstructive airways diseases) are advised to reduce physical exertion and outdoor activities.	Persons with existing heart or respiratory illnesses (such as coronary heart and cardiovascular diseases, asthma, chronic obstructive airways diseases) are advised to avoid prolonged stay in areas with heavy traffic. If it is necessary to stay in streets or roads with heavy traffic, they are advised to reduce physical exertion as far as possible.
51 to 100	High	No immediate response action is suggested. Long-term effects may, however, be observed if exposed at this level persistently for months or years.	
26 to 50	Medium	No response action is required.	
0 to 25	Low	No response action is required.	

Source: EPD (2006a)

5.5.2.3 Emissions inventory

EPD maintains an emissions inventory developed for HK SAR. This is updated annually and is available from 1990 – 2004 (EPD, 2006b). The inventory includes data for particulate matter, SO_2, NOx, CO, non-methane volatile organic compounds (NMVOC) and greenhouse gases. The information can be assessed via the internet, which is convenient for members of the public, researchers, and policy makers. EPD has collaborated with other organisations to develop and update its emissions inventory. For instance, two large power companies - China Light & Power (CLP) Hong Kong Ltd., and the Hong Kong Electric Co. Ltd. (HEC), which had developed their own emissions inventory using different methodologies in order to evaluate their performance, environmental impacts and statutory compliance on environmental protection, have made significant contributions to the development of the inventory. This was achieved through a 2002 technical forum that was set up for EPD, CLP and HEC to present their methods for estimating emissions from the power plants and then achieve consensus. The consensus from the meeting was beneficial to all parties and emerged as an agreed set of emission estimation methods.

5.5.2.4 Air quality modelling

EPD has applied air quality modelling for urban planning and planning development (e.g. ancient building conservation); and for environmental impact assessment (EIA) (e.g. for large factory establishments, construction projects of power plants, the new airport, main roads or any activities that require EIA or planning permission from the Town Planning Department). The modelling software that EPD uses for air dispersion prediction is mostly American such as the: Industrial Source Complex Dispersion Model Short Term Version 3 (ISCST3); California Line Source Dispersion Model Version 4 (CALINE4); Fugitive Dust Model (FDM). Each model is recommended for a different application, for example, FDM is applied for evaluating fugitive and open dust source impacts (point, line and area sources), and CALINE4 and ISCST3 for evaluating mobile traffic emission impacts (line sources) for evaluating industrial chimney releases as well as area and volumetric sources (point, area and volume sources); line sources can be approximated by a number of volume sources. However, both FDM and CALINE4 have a height limit on elevated sources (20m and 10m, respectively). For elevations above these limits, the ISCST3 model or suitable alternative models are used. Furthermore, the ADMS-Urban modelling programme, developed by CERC, UK was also applied to assess whether the residents in a building would be susceptible to the pollution from nearby factories. EPD currently commissioned a comparison of the available air dispersion modelling software in order to select the most appropriate software for use in HK SAR. The findings were expected by June 2005 (pers. comm., Dr. Christopher Fung and Mr. Lau Hin Chung), however, the report has not yet been listed on the EPD website (as of 28 April 2006).

5.5.2.5 Public participation/consultation

EPD promotes public participation in the development of its pollution control programme through a variety of environmental promotions within its Community Relations Programme (CRP). Its mission is to develop community support for desired environmental goals and to encourage the community to contribute to these goals. It aims to develop an improved environmental ethic within the community, which would secure long-term solutions to environmental problems in HK SAR. Examples of activities to enhance community awareness include organising events and action programmes; producing publicity and educational materials; operating a Visitor Centre at the EPD office building, establishing permanent and mobile Environmental Resource Centers (ERCs); providing advice to community groups to arouse community environmental awareness; and liaising with different local interest groups. As part of the CRP, EPD provides a 24-hour hotline to respond to complaints and enquiries on pollution matters. Moreover, EPD has established 'Training the Trainers' programmes that cover different environmental issues (EPD, 2006c).

The programmes, started in schools, aim to engage students in environmental activities, as part of the Student Environmental Protection Ambassador (SEPA) scheme. Primary and secondary school students were included in the scheme to organise and participate in environmental activities on campus. The students received training and wrote reports about their environmental work, and the best efforts were rewarded with a trip overseas or to an environmental leadership summer camp. At this camp, the winners were able to learn more about environmental protection and enhance their leadership abilities. The scheme started in 1995 with 220 schools and 1,659 students as the Student Environmental Protection Ambassadors (SEPAs) (EPD, 2006c). In 2003, there were over 700 schools and almost 12,000 students participating in the SEPA scheme. EPD also helps teachers by providing training courses aimed at achieving better environmental education deliverables with their students. Furthermore, EPD's Hong Kong Green School Award was established for primary and secondary schools to encourage the wider practice of environmental management in schools, with the cash prizes sponsored by the Bank of China (Hong Kong) Ltd. for building resource centres and organic farms.

5.5.2.6 Distribution of and access to air quality information

EPD has an impressive collection of available environment-related databases and publications. These can be accessed electronically at its website http:www.epd.gov.hk or as hard-copy at the EPD head office in Wan Chai. The EPD encourages the public and interested international people to access their information. It also designated a senior Environmental Protection Officer for Management Support, to act as the Access to Information Officer – who is responsible for ensuring that requests for access to information (following the procedures under the Code on Access to Information) are properly dealt with. The large collection of brochures and leaflets produced by the EPD (e.g. Environmental Tobacco Smoke and You; Indoor Air Quality and You; Air Quality Index and You) are bilingually written in clear English and Chinese, and are comprehensible to all readers including to those with no environmental science background. The up-to-date air quality data and emissions inventory can also be found on its website. More advanced research studies such as air quality modelling, and air pollution-related health studies can also be found in the website that show the EPD's transparency in providing the information to all members of the public and other nationals.

5.5.3 Good Urban Governance

From the Asian Development Bank (ADB) Cities Data Book, the HK SAR urban governance is efficient, target-oriented, and open. The system of public administration has been towards greater openness and transparency, especially since 1997. The efficient and target-oriented approach of public administration was aided by the annual budget formulation and target setting (Westfall and de Villa, 2001). The HK SAR administration has demonstrated openness and transparency. For example, all meetings of legislative and district councils, and housing authorities are normally open to the public and televised. Professional and public consultation for major policy documents is allowed before passing through the legal process for approval. In order to keep the public informed, all government bureaus and departments issue their annual reports that can also be accessed via the internet. Furthermore, each government department appoints at least one information officer to provide information requested by either individuals or companies.

5.5.4 Emission Reduction Measures

5.5.4.1 Reduction of motor vehicle emissions

A marked decrease in the levels of PM_{10} and NO_2 within HK SAR has been noticed since 2001, largely as a result of a reduction in motor vehicle emissions (EPD, 2004b). The HK SAR Government budgeted HK$1.4 billion in order to reduce RSP emissions from vehicles by 80% by 2005 and NO_x by 30% (of concentrations in 1999). Under this programme, in 2002, each taxi was offered a HK$40,000 subsidy to convert from a diesel to a liquefied petroleum gas (LPG) fuelled engine. In November 2004, over 18,000 taxis (99% of total taxis) used LPG. Public light buses were also included in the voluntary programme that offered HK$80,000 to each bus to switch to the LPG engine. About 80% of public light buses have converted to the LPG engines. However, the programme for buses was not as successful as that for taxis – mostly because an LPG engine for a bus is more expensive. The remaining diesel vehicles, mainly vans and trucks, are subjected to tighter vehicle control. Since 2002, newly registered vehicles have been required to meet the Euro III standards and were required to meet the more demanding Euro IV standard by 2005. Older vehicles especially light diesel vehicles, (not more than 4 tonnes) must install particulate removal devices in order to be able to renew their licence. Furthermore, petrol stations are required to sell ultra-low sulphur diesel. The penalty for any vehicle producing black smoke was raised from HK$450–HK$1,000. Members of the public can be involved in spotting vehicles producing black smoke on the roads if they attend a half-day training course organized by the EPD. At present, there are over 1,000 members of the public involved in the Smoky Vehicle Control Programme. Under the Road Traffic Ordinance, any smoky vehicle is required to pass a smoke test at a designated vehicle emission testing centre within 14 days, from the day it was reported. The Government also encourages people to use public transport (i.e. trains, buses, and ferries) and more railways are under construction. Also, hybrid vehicles will soon be introduced to HK SAR.

5.5.4.2 Reduction of stationary source emissions

The use of fuel with high sulphur content in industry has been banned in HK SAR since 1990 when there was a serious concern about the emissions produced by small- and medium-sized factories located close to residential areas. Today, most of these factories have relocated to mainland China. HK SAR was left with more problematic stationary sources which are power plants owned by two giant power companies, CLP and HEC. In

1990, these two power companies first introduced natural gas, de-sulphurisation and low NO_x burners, resulting in major reductions in air pollution, although the demand and supply of electricity increased (EPD, 2004b). Significantly, CLP, the major producer of electricity in HK SAR, has used more coal in the past two years, due to a drastic decrease in natural gas supply (Walsh, 2004). CLP announced plans to clean up its coal plants and increase natural gas consumption, however, it will not happen within the next few years. In addition, EPD will set up an effective and flexible mechanism to control the total emissions of SO_2, NO_x and PM_{10} from power stations to achieve their respective reduction targets by 2010 (EPD, 2004b). However, CLP do not expect to see a significant improvement in air quality, perhaps, until 2020 (Walsh, 2004).

5.5.4.3 Indoor air quality

Internationally, improving indoor air quality (IAQ) is one of the most challenging environmental management problems. EPD successfully introduced the IAQ Certification Scheme for Offices and Public Places, a voluntary certification scheme, for indoor air quality into HK SAR in September 2003. Indoor air quality standards for different air parameters were set as the Indoor Air Quality Objectives for Offices and Public Places. The parameters include room temperature, humidity, air movement (flow), CO_2, CO, PM_{10}, NO_2, O_3, and VOCs. The IAQ certification scheme aims to encourage good IAQ management practices and provide an incentive for owners of premises, buildings or property management companies to pursue the best level of IAQ. The IAQ certificate is valid for 12 months. To keep the certificate valid, the organization has to demonstrate compliance with a complete set of standards once every 5 years and with CO_2 and PM_{10} every year. EPD encouraged property owners by advising that good IAQ could enhance the comfort level of occupants, increase productivity of the workers and attract more tenants or customers. For clear guidance on IAQ, EPD also published A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places (EPD, 2003b) and Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places (EPD, 2003c) and several booklets and leaflets.

5.5.4.4 Other emission controls

In order to reduce the emissions of VOCs from printing operations, paints and consumer products for sale in HK SAR, a proposed scheme to require mandatory registration and labelling of the VOC content of specific products will be introduced into the Legislative

Council. High VOC content products will be banned and VOC emission standards for printing operations will be developed in order to reduce ground level O_3 and improve human health especially in respect to people with respiratory illnesses (EPD, 2004c).

EPD pointed out that some developed countries such as the USA, The Netherlands, Sweden and Denmark and other countries in the European Union have set VOC control schemes and eco-labelling for products containing VOCs. Along with other major pollutants, VOC emissions are aimed to be reduced by 55% in the years to 2010, in order to improve air quality in the Pearl River Delta region. The importers or local manufacturers of products will be required to register the VOC contents of each type of paint, printing ink and selected consumer products for which they are responsible. They will be required to produce relevant testing reports, product information and other data. Testing the VOC – containing products must be conducted by proper local or overseas laboratories accredited by the HK Laboratory Accreditation Scheme or certified under ISO 9001 of the International Organization for Standardization or equivalent. Bilingual labelling (Chinese and English) is required to print upon or affix onto individual containers and/re packaging of the concerned products. A penalty ranging from a fine of HK$50,000 – HK$100,000 and up to 6-month imprisonment is proposed to enforce the regulations. Members of the public were invited to give their views and comments on the proposed regulatory framework to the Environment, Transport and Works Bureau before November 2004 by mail, electronic email or facsimile. EPD also published the codes of practice for other hazardous substances such as asbestos, in order to provide guidance and advice to registered asbestos consultants, contractors, supervisor and laboratories on the safe handling of low risk asbestos containing material. In addition, the emergency procedures were provided in the code of practice also available in the EPD website.

5.5.4.5 Regional emission control

The Government of HK SAR realised that the main sources of air pollution are located outside HK and mainly from the Pearl River Delta Economic Zone (PRDEZ). Therefore to improve air quality in HK SAR, the main focus should be upon the encouragement of Guangdong Province to implement enhanced control measures as part of the Regional Air Quality Management Plan (Hopkinson, 2004). The use of cleaner energy is one of the priorities to be achieved by 2005. By 2010, an energy production and supply system will be constructed that will be safe, stable, economical, efficient and clean. In order to control the sulphur contents of fuels, only fuel oil and coal that contain below 0.8% sulphur are allowed to be used. To reduce emissions from coal-fired and oil-fired power stations, flue-gas desulphurisation systems were installed at power plants in Shajioa, Huangpu, Taishan and Zhuhai. Moreover, other measures to reduce emissions in Guangdong include the control of emissions from industrial boilers and processes, emission reduction of VOC from paints, and reduction of exhaust emission from motor vehicles.

5.6 Comparison of Air Quality Management between Hong Kong SAR and Thailand

Air quality management (AQM) in both HK SAR and Thailand was evaluated with respect to conformance to the eight major characteristics of Good Urban Governance (GUG) (Sections 5.1.1-5.1.2) and comparisons drawn between the two countries as follows:

5.6.1 Participation by both men and women

The UN-HABITAT Global Campaign on Urban Governance prioritized gender equity and empowerment of women. Its basic concept is that women and men should have equal access to decision-making processes, resources and basic services, and this can be measured through gender disaggregated data (UN-HABITAT, 2002)

Although most HK EPD staff are male at both operating and managerial levels in air quality management, female staff are also assigned important roles. These include the development of the emissions inventory and management of the indoor air quality voluntary certification scheme. Fewer female staff work in the Air Division, possibly because this type of environmental work may not be as attractive to females – rather than being due to a gender bias in selecting staff (Table 5.5). The Secretary for the Environment, Transport and Works Bureau in Hong Kong is Dr. Sarah Liao, who is very active, knowledgeable and enthusiastic in promoting vehicle emission reduction measures, in particular, the conversion of diesel to LPG engines for taxis and small private buses.

In comparison, although there has never been a female Thai Minister of Natural Resources and Environment, there are a considerable number of female environmental scientists and technicians employed in the Pollution Control Department (PCD) in Bangkok (Table 5.6). At present, Mrs. Mingquan Wichayarangsaridh is a director of the Air Pollution and Noise Bureau of PCD and is an experienced environmental scientist with considerable dedication towards solving air pollution problems in Thailand. The ratio of female to male staff whose responsibilities are related to air quality management in HK EPD and Thai PCD are 1:4.5 and 1:0.5 respectively (see Tables 5.8 and 5.9).

Table 5.8 Number of female and male staff (Environmental Protection Officers and Environmental Protection Inspectors) working in the Air Division of the Environmental Protection Department, HK SAR, China (as of March 2005)

Air Division	No. of female staff	No. of male staff
Environmental Protection Officer	13	62
Environmental Protection Inspector	13	54
Total	**26**	**116**

Source: Ms. Joey Tang, HK EPD

Table 5.9 Number of female and male staff (environmental scientists and technicians) working in divisions under the Air and Noise Pollution Management Bureau, Pollution Control Department (PCD), Thailand (as of March 2005)

Air and Noise Pollution Management Bureau	No. of female staff	No. of male staff
Director	1	0
Industrial Air Pollution Division	9	4
Automotive Air Pollution Division	6	4
Noise and Vibration Division	5	2
Ambient Air Quality Division	5	6
Planning and Evaluation Division	7	2
Total	**33**	**18**

Source: Mr. Montri Chutichaisakda, Thai PCD

In theory, decentralisation equally enables both men and women to participate in local politics in Thailand (i.e., Sub-district Administrative Organization (SAO); Sub-district Municipality (SM); City Municipality (CM)). In 1994, the Sub-district Council (SC) and Sub-district Administrative Organization (SAO) Acts were enacted. The SC members are elected by villagers. One chief executive officers (CEO) and two deputy CEOs are chosen from the elected SC members. There are also government officials working for SAO in supporting roles (e.g. in accountancy, civil work, and technician services).

In 2004, within a total of 215 local government organizations (SMs and SAOs) in Chiang Mai, only 4 females (1.9%) hold chief executive positions (source: Chiang Mai Provincial

Governor Office's electronic data, 2005). In addition, females represented only approximately 15% of all SC members. This shows that participation of women in government at local level in Chiang Mai is low. Therefore, it is important to encourage more women, particularly educated women, to join the local governments as council members. Politically, women should also be given more opportunities to be candidates in local elections. UN-HABITAT (2002) recommended that, in order to promote women to higher management positions, quotas for women representatives in local authorities should be established. Such quota policies may be implemented by the Department of Local Administration, Ministry of Interior (see Section 1.5.1.2 ii).

5.6.2 Rule of law

GUG requires impartial legal frameworks. HK SAR enacted the Air Pollution Control Ordinance (APCO), which is the principal law underpinning the management of air quality. Its regulations cover specific issues related to air pollution, such as motor vehicle fuel and emissions, asbestos control, construction dust and industrial emissions. Pollution from motor vehicles is regulated through both fuel and emission controls. Due to stringent regulations on motor vehicle fuel, the permitted sulphur content of diesel has been progressively reduced from 0.2% in 1995 to 0.035 % from January 2001. Ultra-low sulphur diesel (0.005% sulphur content) became widely available in 2000, and was made mandatory for motor use in 2002. At present, there are over 25 separate pieces of environmental legislation in effect (ordinances and regulations) for air pollution control, such as regulations for the control of construction dusts, open burning and dry-cleaning operations; and for ozone layer protection. EPD also has a key role in enforcing these regulations. The penalties are appropriate to the circumstances relating to an environmental offence. For example, a penalty for any vehicle producing black smoke is HK$1,000 (about 70 pounds sterling) and the vehicle is not allowed to be on the road again until it passes a smoke test at a designated vehicle emission testing centre, controlled by EPD.

In contrast, the situation in Thailand is not as stringent. Under the 1992 Enhancement and Conservation of National Environment Quality Act of Thailand (NEQA) (see Section 1.5.1), temporarily-inhibited vehicle certificates are issued to control vehicles producing black smoke. These must then be modified or improved within 30 days. If there is no improvement within 30 days, a permanently-prohibited certificate is issued and affixed to the vehicle and, if it is found running on the road, the owner will be fined up to 5000 baht (about £70 sterling). While these regulations are enforced in the Bangkok Metropolitan area, there is a lack of systematic action in response to polluting vehicles, which are ubiquitous in Chiang Mai. This applies particularly to 'songtaews', the modified pick-up trucks providing taxi services. Many of these obviously produce black smoke, however, the owners or drivers manage to pass annual inspections conducted by the Chiang Mai Land Transport Office and are able to renew their permits. The different experiences of polluting vehicles between Bangkok and Chiang Mai indicate that enforcement of regulations in the latter city may not be impartial.

Moreover, establishing a suitable framework for legal action to address part of the overall problem of pollution is one of the major problems in Thailand. In contrast to HK SAR, Thailand has yet to develop a unifying, Clean Air Act - as distinct from a set of national environmental acts. The Government of HK SAR enacted its first Clean Air Ordinance to control dark smoke emissions from fossil fuel burning in 1959. It is reasonable to assume that sustainable air quality management will not be possible in Thailand unless a clear and specific Clean Air Act is established. Snidvongs (1993) stated that the enactment of environmental laws and regulations *per se* does not resolve environmental problems in developing countries (including Thailand) because of the lack of effective enforcement, which requires systematic environmental monitoring and stringent application of penalties.

As part of the Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality (1997-2016), the Office of Natural Resources and Environmental Policy and Planning (ONEP) intended to improve outdated laws and regulations with respect to sustainable development and the conservation of natural resources and the environment (see Section 1.5.1.1 ii) (ONEP, 1997a). However, as of April 2006, no new environmental laws and regulations have been enacted according to these plans.

5.6.3 Transparency

Transparency was defined by the UNESCAP as decisions taken and enacted in a manner that follow clear rules and regulations, with freely and directly accessible information available in easily understood forms and media (UNESCAP, 2002). In Section 5.5.2.6 (Distribution and Access of Air Quality Information), the transparency of the EPD, HK SAR in distributing air quality information is explained.

In Thailand, PCD has recently improved its website at www.pcd.go.th. Most publications are available in Thai and can be accessed on-line. For example, publications relating to air quality management include: Fix Your Vehicle for Pollution Reduction; Code of Practice for Dust Control for Construction Activities; Manual for Monitoring of PM in Ambient Air; Manual for Heavy Duty Diesel Engine Maintenance.

Annual reports summarizing the environmental status of Thailand can also be freely accessed through the website. Past and present air quality information at different locations in the national air quality monitoring network including the air quality index (AQI) are available on the PCD website (as of March 2005). Although these publications may not be comprehensive c.f. HK EPD, they provide a good start to providing information to members of the public. Their update frequency is, however, too low to inform the public concerning environmental problems caused by specific pollution episodes. In contrast to HK EPD, many reports on air pollution studies commissioned by Thai PCD are not yet available on-line, but they can be found at the PCD library in Bangkok. This library is not convenient for people living outside Bangkok. In addition, daily air quality data outside Bangkok are reported on-line, for 16 provinces, but not for Chiang Mai (http://www.pcd.go.th/AirQuality/Regional/defaultThai.cfm). Although PCD reports the Air Quality Index (AQI) and advice to the public on-line, it does not report daily air quality in Chiang Mai (as of April 2006).

In Chiang Mai Municipality, there is only a large wooden board, located in a corner of the Old City Moat that manually reports daily air quality. This is not an appropriate method for reaching the majority of the municipal population. It is also often inaccurate. For example, in February–March 2004, when city air pollution was severe, 'medium' air quality was reported on the board. It has been estimated that almost 90% of Chiang Mai residents never receive air quality information (see Section 3.4.4) and a more appropriate method of providing air quality data needs to be developed (see Chapter 6).

5.6.4 Responsiveness

GUG requires institutions and processes to serve all stakeholders within a reasonable time frame (UNESCAP, 2002). HK EPD and Thai PCD both provide a 24-hour hotline to respond to environmental complaints and enquiries. Information on the subject matter of public complaints can be found on the EPD website. EPD claims that it has suitable complaint handling capabilities and has used information received to refine its enforcement and prosecution capacities. Experience has shown that Hong Kong people readily complain when they perceive pollution-related damage is being done either to their environment or to themselves. In 2000, there were more than 25,000 complaints about worsening smog, particularly during high Air Pollution Index days. There is currently no hotline for public complaints related to environmental problems in Chiang Mai. Moreover, the author doubts the capacity of complaint handling procedures in Chiang Mai to respond effectively to public complaints.

Photographed by K. Sriyaraj

Figure 5.13 Typical smoking during the brick production process in Patal Village in Hangdong district, Chiang Mai

Mr. Pathom Puapansakul's case is an example of complaint handling failure in Chiang Mai. Mr. Puapansakul, a retired lecturer from Chiang Mai University, invited the author to observe air pollution sources from brick production activities adjacent to his residence in Patal Village, Hangdong District in March 2005. He informed the author that three of his immediate neighbours manufactured bricks for use in construction – a customary practice in this village. In this process, wet bricks are piled up together with sawdust approximately 2m high, and are burnt continuously until dry. This normally takes at least 36 hrs in the dry season and up to 7-10 days in the wet season (see Figure 5.13). Smoke, gases, particulate matter and odour are produced during the open burning of bricks. Mr. Paupansakul also stated that the smoke and fine dust from these open burning activities caused him and his wife allergic respiratory symptoms. He had complained to the head of Patal village and a responsible local government organization several times, but no action was taken against the polluters. Mr. Paupansakul then made his complaint to some organizations at a provincial level, however, they neither gave a positive response nor took actions to resolve the problem. Mr. Puapansakul has ceased making his air pollution complaints due to the lack of responsiveness of the governmental organizations in Chiang Mai.

Photographed by K. Sriyaraj

Figure 5.14 Illegal dumping and burning of domestic waste in the wood behind the Provincial Hall, Chiang Mai, Thailand as of 20 January 2005

In 2005, waste burning remained ubiquitous in urban, suburban and rural areas in Chiang Mai Province, which was identified as a key cause for concern among Chiang Mai residents regarding air pollution. This is so, even in areas where domestic waste burning is prohibited, e.g., in the wooded areas behind the Provincial Hall (Figure 5.14). Here fire was regularly set to burn wastes and sometimes it was observed to be out of control. For example, on Saturday 26 February 2005, a fire was noticed at noon and reported to Chiang Mai Municipality so that it could be extinguished. It started as a small fire burning wastes, but the subsequently damaged woodland area was approximately 30,000 m^2. The fire was stopped around 4:30 p.m. Later, in March 2005, the Chiang Mai Governor attempted to discourage people from burning forested areas and domestic wastes, setting up a local hotline for reporting forest fire incidents and illegal burning (0 5389 0000 (Air Pollution Emergency Call Center)). After receiving an emergency report, the center contacts the local government body responsible for that area to investigate the fire and to give warning, if possible, to the person who set the fire. However, this can only be a short-term measure.

More stringent regulations and enforcement are needed for controlling open burning in the longer term, as well as effective waste collection as part of a comprehensive waste management system (see Chapter 7).

5.6.5 Consensus oriented

Because government is not the only participant in urban governance and since there are different opinions and interests concerning urban issues among other stakeholders (e.g. NGOs, research institutes, civil society) (UNESCAP, 2002), government cannot achieve a broad consensus without contributions from other organizations.

EPD allows all stakeholders to take part in environmental management and promotion. An example is the development of a set of emission calculations for power plants with the cooperation of Hong Kong's two major power generation companies, CLP and HEC. One of EPD's responsibilities is to develop and update emissions inventories. However, CLP and HEC have developed their own emissions inventories for the key air pollutants (i.e. SO_2, NO_2 PM_{10} and greenhouse gases), based upon their power generating processes using fossil fuels. EPD worked together with the two companies in order to ensure the use of consistent emission factors and calculation methods. By working closely with CLP and HEC, the power companies are committed to improving their performance in reducing air pollutant emissions.

EPD also works closely with academic institutions such as the Hong Kong Polytechnic University, Hong Kong Baptist University and the University of Hong Kong, sponsoring air pollution research studies at these institutes. An example of such studies is the *Characterisation of Hydrocarbons, Halocarbons and Carbonyls in the Atmosphere of Hong Kong* (Guo *et al.*, 2004) conducted by the Hong Kong Polytechnic University and EPD. Another example is the Workshop on Emission Source Characterisation (10-11 November 2004, HK and Shenzhen, South China), which the author attended. Its main objective was to allow the scientific community to help address issues related to regional air pollution sources within the Pearl River Delta (PRD). It was jointly organized by EPD, Air & Waste Management Association, Hong Kong Polytechnic University, Hong Kong University of Science and Technology and Peking University; and financially supported by the Hong Kong Institution and Shell (Hong Kong) Ltd. This event gave an opportunity for people with an interest in air pollution to meet, including the Civic Exchange – an independent Hong Kong-based public policy think-tank. These activities demonstrate that EPD has gone some way in adopting a consensus orientation in air quality management.

Thai PCD and the Department of Land Transport (DLT) developed the Developing Integrated Emission Strategies for Existing Land Transport (DIESEL) programme to establish a comprehensive understanding of in-use diesel vehicles, testing various emission control options, and improving decision-making for better urban air quality in Asian cities. Bangkok was chosen the pilot city for implementing the DIESEL Programme. International partners included the World Bank, US AEP, US EPA. Foreign companies (e.g. Volvo and Lubrizol) and Thai companies were also involved in the implementation (PCD, 2004b).

In Chiang Mai, two stakeholder meetings about air quality management were organised in 2002 by the local government partners of the MAQHUE project and financed by the European Commission (EC). Other meetings during 2001–2002 were organized by Chiang Mai Municipality and PCD; financially supported by the US EPA and the State of Maryland, USA. Without international financial support and advice, it is questionable whether local governments in Chiang Mai would be able to organise and maintain stakeholder meetings for the discussion local air pollution issues.

5.6.6 Equity and inclusiveness

UN-HABITAT (2002) considered people to be the principal wealth of cities as well as both the object and the means of sustainable human development. On this basis, all citizens should, therefore, actively contribute through participation in the decision-making processes.

To ensure that the initiative to improve air quality in HK SAR is inclusive, all citizens are given the opportunity to comment on any consultation documents issued by EPD. EPD includes public and professional consultation in its systematic requirements for all major policies before passing them through the legal process for approval. As of 30 September 2004, the Government of HK SAR published 61 environmental impact assessment reports (EIAs) – all available for public consultation and review. Recent EIA reports concern a Feasibility Study for Waste-to-energy Incineration Facilities; the Recovery Park in Tuen Mun Area 38; and the Animal Cremation project. Under the EIA ordinance, all members of the public are allowed to share their opinion on new developing projects through the EPD website. There are 2 'windows', the presentation of a profile of project development and, subsequently, its environmental impact assessment (EIA) report. EPD works with other government departments and private developers to provide the EIA reports for public comment and ensure continuous public involvement in any major projects that may affect the environment.

In Thailand, the 1992 Enhancement and Conservation of National Environmental Quality Act (NEQA/92) recognizes the legal rights of Thai citizens with respect to environmental protection (Harashimi, 2000). Box 5.1 contains part of Section 6 of the Act regarding the prominent position taken by public participation in environmental protection. However, Shytov (2005) criticised this part of the Act as follows;

> *"There are two major weaknesses of the Act. The first is that these general propositions on public participation have found very little, if any, development in the rest of this important statute. The second weakness is rooted in the wording of the general provisions on public participation, which <u>may be accorded to individual persons</u>... but may not. In this respect, the wording of the Act sounds as nothing more than a general policy statement."*

Moreover, its statement (in Box 5.1) "*...except information or data that are officially classified as secret intelligence pertaining to national security...*" could be used to control the disclosure of information. This Act does not provide both a mechanism and clear conditions under which the secrets pertaining to national security or trade and business must be disclosed to the environmental authorities (Shytov, 2005).

In fact, public consultation, particularly regarding government consultation documents and EIA reports such as those promulgated by HK SAR, has never been facilitated in Thailand at either the national or local level. From policy development to approval processes, they were all conducted within Government circles – from department level to ministerial level. If members of the public disagreed with either draft policies or regulations, there was no mechanism by which they could object officially. Objections may only be openly expressed at occasional environmental demonstrations, which often cause political difficulties for the Thai Government. With media coverage on environmental issues, a significant impact on society has been created such as gaining official response and the cooperation of related institutions and public concern. For example, a plan to construct a waste-burning electric power generation plant in Hangdong District, Chiang Mai, which would be a probable significant source of air pollution, was withdrawn in 1995 due to strong protest from local communities (Harashimi, 2000).

Box 5.1 Part of Section 6 of the 1992 Enhancement and Conservation of National Environmental Quality Act

The 1992 Enhancement and Conservation of National Environmental Quality Act

Section 6 of the statute states:

"For the purpose of public participation in the enhancement and conservation of national environmental quality, the following rights and duties may be accorded to individual persons as provided by this Act or governing laws related thereto;

To be informed and obtain information in matters concerning the enhancement and conservation of environmental quality, except information of data that are officially classified as secret intelligence pertaining to national security, or secrets pertaining to the right of privacy, property rights, or the rights in trade or business of any person which are duly protected by law;

To be remedied or compensated by the State in case damage or injury is sustained as a consequence of dangers arising from contamination by pollutants or spread of pollution, and such incident is caused by any activity or project initiated, supported, or undertaken by a government agency or state enterprise;

To petition or lodge a complaint against the offender in case of being a witness to any act committed in violation or infringement of the laws relating to pollution control or conservation of natural resources;

To co-operate and assist government officials in the performance of duties relating to the enhancement and conservation of environmental quality;

To strictly observe the provisions of this Act or other laws concerning the enhancement and conservation of environmental quality."

Source: Cory *et al.* (1998)

Shytov (2005) also commented that although NEQA/92 requires scientific expertise to underpin the preparation of EIA reports, the Thai people do not generally trust those EIA reports that are required for submission to ONEP (according to his discussion with Mr. Somchai Prichasilapogun, an expert in Thai public participation law). The main reasons include: i) most EIA reports are too technical and some of them are in English (and hence not comprehensible to general members of the public); ii) it is difficult for an interested person to obtain a copy of an EIA report (they are not yet accessible through the Thai Government's websites); iii) some EIA reports were produced only after a political decision by the government or an authoritative body had already been made (i.e. to initiate large development projects); iv) some EIA reports prepared for the pacification of the public contained much false and inaccurate information (Shytov, 2005). Although there is sanction for the submission of such information, it was noted that this control has never been exercised unlike in HK SAR and many developed countries where it is the duty of the responsible environmental organisations to place copies of EIA reports on public display before a license or permission is granted, and to invite the public to comment before public hearings take place (Shytov, 2005). To gain public trust, it is urgent that the Ministry of Natural Resources and Environment resolves these problems.

NEQA fails to specify the rights and the duties of Thai citizens with respect to the protection of natural resources and the environment (Shytov, 2005). Towards the resolution of the above problems, the latest Constitution of Thailand (1997) addressed this issue by specifying citizen's rights as follows: The Right to Information (Article 58); the Right to Public Hearing (Article 59); the Community Right to Environmental and Resource Management (Article 45); the Right to a Decent Environment and EIA Requirements (Article 56) (Harashimi, 2000). During the drafting of the 1997 Constitution, a series of 'public hearings' were organized by the Constitutional Drafting Assembly (CDA), which had members in all provinces. Public opinions on the draft constitution were gathered by the CDA members. As a result, the 1997 Constitution recognises more rights and freedoms than any other previous Constitution (Uwanno and Burns, 1998). It may be too early, however, to see significant improvements by government departments, whose responsibilities involve natural resources and the environment, to positively and actively respond following the latest Constitution.

5.6.7 Effectiveness and efficiency

GUG requires institutions to produce results that meet the needs of society while making the best use of the resources at their disposal. In this respect, UN-HABITAT (2002) focused upon cost-effectiveness in the management of revenue sources and expenditure, as well as in the administration and delivery of public services.

EPD (HK SAR) has a hotline centre called the 'Customer Service Centre' (tel. (852) 2385 1018). It is automatically and bilingually (English and Chinese), operated 24 hours per day, and allows members of the public to make enquiries concerning all aspects of environmental pollution (e.g. air, water, solid wastes). Calling at 01:40 p.m. on 24 December 2004 (Thailand time), the author required less than 5 minutes to receive all of the information requested concerning the most recent general Air Pollution Index (API) at 1 p.m. in HK SAR. The service is user-friendly and well managed with an option to return to the main menu to enquire about advice to the public when the API is greater than 100. It also allows callers to enquire about APIs and provides forecasts for specific areas/roads within the territory. The author also made a phone call to enquire about general methodologies for developing the emissions inventory. A female junior Environmental

Officer responded whose responsibility was the development of part of the emissions inventory. The answers provided were satisfactory, although detailed methods could not be clearly explained on the phone; and accordingly, she offered to send the requested information by email. HK EPD strives to achieve high standards of public responsiveness that are effective, efficient and up-to-date. EPD staff members are well-trained, service-minded and friendly to callers.

In contrast, the Thai PCD does not generally deal with public complaints effectively – due, at least in part, to a lack of technical knowledge concerning environmental issues. By requesting the same information from PCD as from HK EPD, the author had a less than satisfactory telephone conversation with a junior PCD staff member (e.g. too long spent on hold or being transferred to too many people and culminating with inadequate or indirect answers to the questions asked). In addition, the PCD hotline (Chemical Emergency Response Supporting Center Hotline; tel. 1650) often has no person answering the phone, especially outside normal working hours, even though it should operate a 24-hr emergency service. In addition, the one senior PCD staff member appointed to be a focal contact person for public complaints or requests via the hotline was unable to answer all environmental questions. These examples demonstrate current PCD difficulties in the management of public complaints relating to environmental issues. It is believed that PCD requires fundamental changes to its internal culture and public interface before an effective HK-style 'One Stop Services' call centre can be developed for Thailand.

The GUG concept of efficiency also covers the sustainable use of natural resources and the protection of the environment. Sustainable measures for local air quality management in Chiang Mai based on sustainable use of natural resources will be discussed in Chapter 6.

5.6.8 Accountability

UN-HABITAT (2002) explained that the accountability of local authorities to their citizens is a fundamental principle of good governance. There should be no tolerance of corruption in well governed modern cities. Corruption undermines local government credibility and can deepen urban poverty. Transparency and accountability are crucial to stakeholder understanding of local government and to the people who may be affected by its decisions and actions. Access to information is also fundamental to good governance and laws and public policies should be applied in a transparent and predictable manner. Both elected and appointed officials as well as other civil servant leaders must demonstrate high standards of professional and personal integrity. HK EPD policy is clear concerning its accountability and transparency.

In Thailand, members of the public are generally unaware of the decision-making processes concerning either crucial draft laws and regulations or projects in development. The media (mainly TV and newspapers) are the only possible source of public information and then only when significant problems occur. For example, a very large wastewater treatment plant in Klong Daan, Samutprakarn province, was left unfinished due to project mismanagement. At a provincial level, members of the public are allowed to 'indirectly' participate through politically-elected local governments (i.e. Provincial Administration Office and Tambon (Sub-district) Municipalities or smaller local political groups) at a grass-roots level, but are not allowed to be involved in decision making processes relating to local issues (e.g. road construction, domestic waste disposal). Project management and budget details for any investment in construction and pollution control projects are presented in reports produced by these local governments, but unfortunately they are often distorted, or in the worst-case, no information is released to the public. This demonstrates that at both national and local levels the Thai government has failed to be accountable to the public.

This is confirmed by a statement by Mr. Kesem Snidvongs, former Permanent Secretary of the Ministry of Science, Technology and Environment, as follows;

> "*...due to lack of effective (environmental) monitoring and enforcement, our (Thai) system of governmental management has suffered from 'abuse of power'. This abuse has been common practice both by project proponents, like factory owners, mine owners, forest concessionaires and other degraders, and by the government officials responsible for controlling the environmental operations of the project proponents.*" (Snidvongs, 1993)

5.7 Conclusion

The principles of Good Urban Governance (GUG) provide an international standard of governance or management of cities. In this study, eight GUG characteristics - developed by UNESCAP (2002) - were used in assessing environmental management, particularly air quality management (AQM) in Thailand, compared to Hong Kong SAR.

Comparisons between HK SAR and Thailand clearly show significant differences in urban governance and environmental management, especially with respect to air quality. It appears that HK SAR is well managed, and has established an advanced, transparent and public-based decision making and implementation process. In terms of air pollution, one of the major problems needing prompt resolution is the trans-boundary migration of air pollution emitted from different sources in the PRDEZ. Local problems in HK SAR include old heavy diesel vehicles (e.g. buses) which still cause significant street level air pollution and constitutes a nuisance and health hazard for pedestrians. Construction sites still produce dust (e.g. in front of the Peninsula Hotel). Ferries using diesel still produce black smoke and are considered a health risk to people with cardio-respiratory diseases. The use of coal rather than cleaner natural gas by power stations is another cause for concern since emissions of SO_2 and other pollutants are projected to increase. However, the concept of Good Urban Governance (GUG) is considered one of the key tools in environment protection by the Environment, Transport and Works Bureau, HK SAR and would undoubtedly assist Thai government departments such as PCD to effectively tackle current and future environmental problems.

In Thailand, a major obstacle to the solution of environmental problems is the outdated set of associated laws and regulations, in which the rights of Thai citizens are often significantly restricted in decision-making processes. This is apparent in issues related to information disclosure in the promulgation of Environmental Impact Assessment (EIA) reports. In areas pertaining to environmental protection, government at both the national and local levels, has consistently failed to show transparency, responsiveness and efficiency of administration. Moreover, the partial enforcement of environmental regulations towards polluters and a demonstrable lack of accountability by many authorized government officials, obstructs improvement in environmental management at a national level.

At a local level in Chiang Mai, few females have been promoted to managerial roles in local government organizations. In Chapter 6, the problems associated with a lack of GUG within local government in Chiang Mai are considered specifically and sustainable measures for local air quality management are recommended – based on both GUG principles and current knowledge and technologies suitable for the Chiang Mai situation. Measures which may assist Chiang Mai to be more self-sufficient and better able to produce its own consultation resources (e.g. an air enquiry call centre; air quality and respiratory health educational publications; stakeholder dialogues; Clean Air exhibitions and other events; environmental education packages for young generations in schools and local farmers; an efficient public transport system) are also addressed. Such local participation would be expected to lead ultimately to a better consensus on air quality management issues within all sections of society.

CHAPTER 6

INVESTIGATION OF CURRENT AIR QUALITY MANAGEMENT POLICIES AND PLANS IN THAILAND

6.1 Introduction

In Thailand, the ninth National Economic and Social Development Plan (NESDP) (2002-2006) was designed to provide national guidelines for the development of economic and social policies. It is intended that all government organizations follow the NESDP policies when producing their development strategies. This is true, not only at a national level, but also at the provincial and local level. Since 1995, following the promulgation of the Tambon (Sub-district) Council and Tambon Administrative Act (1994), authority and responsibility have been decentralised from central to local government organizations (Sopchokchai, 2001). At a local level, Sub-district Municipalities (SM) and Sub-district Administration Organisations (SAO), the fundamental governing units, are now responsible for local administration and the management of incomes and funds. Provincial and local government organisations are required to set up action plans and policies (e.g., environmental management) and to disseminate these to people in their different areas of responsibility.

This chapter focuses on the assessment of existing environmental management (EM) plans at the national, provincial and local levels. The aim was to confirm the existence of air quality management (AQM) within plans and to ascertain the level of priority given to these. Also to determine how effectively national environmental policies were disseminated to local governmental organisations following the decentralisation approach. Prior to recommending sustainable measures to improve air quality in Chiang Mai (Chapter 7), existing AQM aspects need to be assessed with respect to their effectiveness for resolving air pollution problems in the province. Key research questions for this chapter are: Why is the air pollution problem in Chiang Mai not properly and holistically addressed?; Why does local AQM not really function in the province? The main objectives of the work undertaken for this Chapter are as follows;

i) To investigate the prioritisation of environmental problems by governmental organisations in Chiang Mai, with respect to air pollution.

ii) To determine what aspects of local administration should be improved to better manage air quality.

6.2 Methodology

The methodology employed for this chapter comprised an assessment of environmental management at national, provincial and grass root levels - in terms of vision, capacity, and planning – as employed for tackling environmental problems, particularly those caused by air pollution.

i) **National level:** The following national plans and policies were reviewed and assessed: The *9^th^ National Economic and Social Development Plan* (NESDP) *(2002-2006)*; the *Government Management Plan (2005 – 2008)*; ONEP's *Policy and Perspective Plan for Enhancement and Conservation of National Environmental Quality (1997-2016)*; PCD's *Pollution Prevention and Mitigation Policy* (1997-2016); Environmental Education (EE).

ii) **Provincial level:** The *Integrated Strategy of Development for Chiang Mai Province B.E. 2547-2550 (2004-2007)* was reviewed including fund allocations to development projects in Chiang Mai Province, which were assessed particularly when they related to air quality improvement (e.g. AQM). This integrated strategy is the most recent strategic plan for Chiang Mai Province (Chiang Mai Provincial Office, 2003). Provincial budget details, including allocation of funds to a range of development projects in the province were also thoroughly analysed. A key question is whether air quality management is one of the major concerns at a provincial level. The budget details for development projects available from 2004 – 2005 were translated from Thai into English and are given in Tables 6.1 and 6.2. The percentage allocation of budget for each project was also calculated to determine what the fraction of the available funds allocated to projects related to the environment.

iii) **Local level:** A questionnaire survey was conducted in order to assess the current level of environmental and air pollution awareness among SM and SAO officials at both executive and operational levels. Key research questions were: i) Was environmental management included in their strategic plans?; ii) If it was included, which environmental problems (e.g. water, air pollution) were their main concerns?; iii) If air pollution was a cause for concern, what action was applied to solve the problem? For example, to determine whether air pollution is viewed as a major cause for concern, the respondents were asked what approaches or actions have been undertaken to prevent air pollution and whether they are technically and financially capable of conducting local air quality management (LAQM). The detailed methodology of questionnaire design, administration and the analysis of results are as follows:

The title of the questionnaire was 'Environmental Management Vision of Local Government Organisations in Chiang Mai'. The questionnaire consisted of 5 questions as shown in Table 6.1. These were based upon the results of a discussion with Mrs. Thitirat Intaping, Plan Analyst, Pong Yang Sub-district Administration Office, who was responsible for drafting the annual strategic plan and 3-year development plan of her organization. Generally, SM and SAO development plans cover 6 topics - basic infrastructure; human resources and society; local economic conditions; education, religion and culture; water resources (e.g. irrigation); natural resources and environment. The first question was an opening general question that led to the second question which asked each respondent to identify environmental pollution problems in his/her area of responsibility. The third and fourth questions requested information about past, present and future LAQM action plans. The fifth question was designed to determine whether the respondents think that the plans produced are fit for purpose. In order to avoid bias, the respondents were not told the true objectives of the survey (to assess LAQM capacities and determine whether air pollution problems are given sufficient priority within each sub-district). However, they were verbally informed (when handing out the questionnaires) that the questionnaire aimed to assess the EM capacity of local government organizations.

Questions 1 to 4 were designed to obtain factual information and Question 5 aimed to obtain opinions. The questionnaire design did not directly focus on the prioritization of LAQM, because it was expected that most SMs and SAOs in Chiang Mai had inadequate capacity in terms of human and financial resources to deal with this aspects of EM. Instead, the questionnaire survey aimed to investigate the current environmental, as well as administrative, problems of local government organizations, with particular respect to air pollution. The results of the questionnaire were expected to illustrate EM problems, particularly LAQM, among these organizations and to investigate the causes that obstruct the improvement of air quality in Chiang Mai. Ultimately, the investigation was conducted to indicate how practical the decentralization of EM was in Thailand, using, as an example, SMs and SAOs in Chiang Mai.

Table 6.1 List of questions in the questionnaire used for the assessment of air quality management capacity and environmental awareness within local government organisations in Chiang Mai

Questions	Type of question
1) What are the priorities under the strategic plans of your organization? i) Development of basic infrastructure ii) Development of human resources and society iii) Economic development iv) Development of education, religion and culture v) Development of water resources vi) Improvement of natural resources and environment vii) Others, please specify…	Semi-open
2) Please list major environmental problems in your areas of responsibility.	Open-ended
3) What environmental projects were undertaken in your areas of responsibility in the past few years? Please summarise the project details including obstacles during implementation, budgets (baht) and its sources. i) Water resource ii) Air pollution iii) Domestic waste management iv) Agriculture v) forest conservation vi) Others	Open-ended
4) Did your organisation include an environmental management plan in the 3-year development plans (2005 – 2007)? Please briefly summarise the plan.	Open-ended
5) Do you expect that the environmental management plans in 4) will improve the environmental quality in your local area? How will it work?	Open-ended

One hundred and one copies of the questionnaires were distributed to participants at a workshop on the Revision of the Comprehensive Urban Plan for Chiang Mai organised by the Chiang Mai Office of Civil Works and Town and Country Planning (CMOPT) in January 2005. The questionnaires were intentionally given to the participants from SMs and SAOs (judgment sampling) with workshop handouts when they registered for the workshop. A code was assigned to each workshop participant on CMOPT's list and this code was written on the questionnaire for identification of the respondent's position (e.g. whether at executive or operational level). The questionnaires were not required to be anonymous because the survey was intended to obtain information about their organisations (e.g. asking about their environmental policies) rather than personal information (Jarrett, 2004).

The main limitations of this questionnaire survey include:

- Bias: The results of any questionnaire survey depend greatly on the respondents telling the truth. Some respondents may reply that their organizations included EM in their strategic plans although actually there may be no EM plans. Ideally, the information regarding the EM plans of local organisations would be obtained from their reports of strategic plans. However, to obtain these reports from all local organizations in Chiang Mai within a limited timeframe was impossible because most of these organisations do not normally distribute such reports (with expenditure and budget details) to members of the public.
- Unpredicted problems: Originally, the self-administered questionnaire in this study was designed only for chief executive officers (CEO) of SMs and SAOs. However, it was found that the majority of such managers did not attend the workshop, but sent their staff (e.g. technicians, legal advisors) to the workshop. In order to avoid inadequate numbers of completed questionnaires, the questionnaires were also given to these representatives, who were not able to answer all of the questions. Some questions (e.g. Questions iii and iv) may have addressed issues beyond their level of authority or they may not have been directly involved with environmental policies and plans, which may indicate the lack of participation in decision-making processes within the organisation.
- Pilot survey: A pilot survey was not conducted as part the questionnaire design process. As mentioned above, the questionnaire was constructed based upon discussions with an experienced plan analyst. The author also adjusted the questionnaire after discussions with other colleagues (e.g. CMOPT officials) to ensure that the questions were understandable. However, after the questionnaires were completed, it was found that questions about budgets used for environmental projects were mostly left unanswered, although the project details were given. This may be because information about expenditure was treated as confidential, or it could not be recalled at the time.

In the workshop, 79 participants (out of 101) returned the completed questionnaires. Each completed questionnaire was reviewed to establish whether each SM/SAO includes air quality management in their 3-year strategic plan. The questionnaires were separated into 2 groups – those answered by executive officials (CEO, Deputy CEO, Executive Secretary); and by operational officials (civil engineer, construction technician and plan analysis officer). The results of the questionnaire survey are presented in Section 6.5.

6.3 Environmental Management at the National Level

6.3.1 The National Economic and Social Development Plan

The 9th NESDP (2002 – 2006) is a strategic plan that serves as a framework for medium term national development, consistent with its long term vision. It has 4 objectives: promotion of economic stability and sustainability; establishment of a strong national development foundation; establishment of good governance; reduction of poverty and empowerment of Thai people [National Economic and Social Development Board (NESDB), 2001]. A priority goal is the pursuance of good governance at all levels of Thai society in order to achieve real, sustainable, people-centred development. Following the 8th NESDP (1997-2001) and the 1997 Constitution, the 9th NESDP emphasises public participation in all sectors of society (de la Rosa, 2002). For environmental aspects, natural resources and environmental management (NREM) was included in the national economic and social development strategies (see Box 6.1). Other strategies relate to sustainable rural and urban development and include the empowerment of communities (i.e. participation of all stakeholders in community development) and the development of liveable cities. Furthermore, capacity building is identified as being required to equip local administrative organisations with well-trained staff and to provide effective management systems in order to support decentralisation (NESDB, 2001).

One of the 9th NESDP priorities is to improve environmental quality as part of its quality of society goal. Ideally, this involves raising public awareness and the participation of local people in the conservation and rehabilitation of natural resources and the environment. The development of waste disposal systems is prioritised under the pollution abatement strategy. However, there is no specific strategy for air quality management, including air pollution control and abatement. Air pollution is not prioritised (actually it is not mentioned at all), whereas the preservation of bio-diversity is a stated priority, in addition to the efficient utilisation of water resources, and the restoration of soil fertility. Furthermore, strict environmental law enforcement was mentioned in the 9th NESDP, but the guidelines by which this should be achieved were not given. However, the environmental policies stipulated in NESDP were further developed into action plans by responsible government departments. Consequently, the ONEP's Policy and Perspective Plan for Enhancement and Conservation of National Environmental Quality (1997-2016)

(Section 6.3.3) and the PCD's Pollution Prevention and Mitigation Policy (1997-2016) (Section 6.3.4) were produced.

Box 6.1 Natural resources and environmental management (NREM) strategy as part of the 9th National Economic and Social Development Plan

Natural resources and environmental management (NREM) strategy

i) Upgrade the efficiency of natural resources and environmental management in support of conservation, and rehabilitation and development of the grassroots economy.
Existing mechanisms for natural resources and environmental management should emphasise local participation. Public awareness regarding environmental quality, and implications for a better quality of life, should be enhanced, together with more efficient law enforcement. An environmental database, at a local level, should be established to facilitate efficient monitoring and evaluation.

ii) Preserve and rehabilitate natural resources.
Actions should be taken to protect and demarcate preservation and conservation areas in order to maintain eco-system balance and promote land use consistent with capability and best use. As part of the natural resource strategies, the preservation of bio-diversity should be prioritised as well as an efficient utilization of water resources, and the restoration of soil fertility.

iii) Rehabilitate and preserve community surroundings, art and culture, as well as tourist attractions in order to enhance the quality of life and the local economy.
Actions should be taken to preserve natural tourist attractions, local arts, and archaeological sites in order to support sustainable development of tourism. Town planning should be used as a mechanism to coordinate environmental management in cities to achieve liveable and viable cities.

iv) Manage efficient pollution abatement leading to the development of liveable cities and communities.
Resources should be focused on the development of waste disposal systems that are acceptable to communities. Pollution abatement requires strict law enforcement, the adoption of appropriate technologies, and the upward adjustment of environmental standards to international levels.

Source: NESDB (2001)

6.3.2 The Government Management Plan

After the general election in Thailand, on 6th February 2005, the Government Management Plan (GMP) (2005 – 2008) was drafted. Subsequently, this was then approved by the Cabinet on 12th April 2005, led by Dr. Taksin Shinawatra, the Prime Minister. The GMP provides a framework and guidelines for government agencies, at ministerial to local administration levels, concerning their roles and responsibilities. Its strategic framework, under this 4-year plan, comprises 9 major strategies as follows: i) poverty eradication; ii) human potential and social development; iii) economic restructuring for balanced and sustainable development; iv) management of natural resources and environment; v) international relations and economic activities; vi) development of laws and promotion of good governance activities; vii) promotion of democracy and civil society; viii) maintenance of government stability; ix) preparation for globalisation and changes.

For this study, Strategy iv, management of natural resources and environment, is of particular significance and was subjected to analysis to determine whether air quality management is appropriately prioritised by the Thai Government. In the GMP, the indicator for accomplishing Strategy iv is that environmental quality measures (for air, water and noise) remain within national standards. Eight key operational plans for the management of natural resources and the environment are listed in Box 6.2.

Of the strategic plans for the management of natural resources and environment [as part of the Government Management Plan (GMP) for 2005 – 2008], the only plan related to air pollution abatement is that which promotes the use of cleaner fuels and low emission motor vehicles (see Section 6.2.1.2 vii). Similarly, the only prioritised environmental issue in the 9th NESDP is solid waste management (e.g. industrial and hazardous wastes). With respect to industry, only the energy sector is considered and other polluting industries such as the petrochemical industry, agro-industry, ceramic industry and rice mills are ignored. The 2nd operational plan under Strategy iv) suggests charging local people for environmental management (Box 6.2), but this is unrealistic. For example, most local administration organisations in Chiang Mai have yet to establish their environmental management system and under such circumstances charging is an irrelevance (discussed in Section 6.3.3). It is suggested that perhaps it would be better if polluters were charged for the cost of improvements through environmental management, in accordance with the 'polluter pays' principle.

Box 6.2 Operational plans under Strategy iv) (management of natural resources and environment) of the Government Management Plan (2005 – 2008)

Strategy iv: Management of Natural Resources and Environment
Operational plans

1) Support of the use of environmentally friendly products and services.
2) In order to efficiently manage the environment at a local level, a charging system should be developed for environmental management. Its incentives should be explained to local people. The capacity building of human resources should be undertaken, and existing environmental regulations should be improved.
3) Reduce (at source) and reuse industrial wastes, also apply information and computer technology to waste management systems.
4) Group business, community and private sectors in order to jointly establish waste management systems. Elevate the value of wastes as well as reduce the quantity of wastes entering waste disposal.
5) Financially support the producers of recycled and/or easily disposable products.
6) Establish laws to prevent the import of dangerous substances, including solid and industrial wastes.
7) Promote the use of cleaner fuel and low emission motor vehicles.
8) Control any environmental impacts that may be caused by the energy sector, such as those produced by electric generators and oil refinery industries.

Source: Government Management Plan (2005-2008)

It can be seen that both the 9^{th} NESDP and GMP failed to holistically address environmental problems in Thailand, especially those relating to air pollution. Air pollution, it would seem, is not a major concern of the Government; neither does the Government seem to appreciate that air pollution has become a significant problem in many developing urban areas scattered throughout the provinces of Thailand. It is possible that this is because the planners and decision makers who drafted the 9^{th} NESDP and GMP did not place a high priority on environmental management, particularly LAQM. In addition, the environmental problems detailed in these plans are only partly defined and not properly categorised, for example, into air, water (wastewater, coastal water, freshwater, ground water), solid wastes (domestic, industrial, hazardous) and soil. It is suggested that unclear and non-specific strategic plans may confuse governmental organisations at all levels.

6.3.3 The Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality

The Office of Natural Resources and Environmental Policy and Planning (ONEP) established the Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality (hereinafter referred as 'the prospective plan') for 1997-2016. It provides a framework for the conservation of the environment and incorporates environmental quality management plans to cover various sectors (ONEP, 1997a). In general, the prospective plan focuses upon integration of natural resource management and conservation, and improvement of environmental quality, in sustainable manners (ONEP, 1997b). There are 6 major policies covering the following environmental issues: natural resources; pollution prevention and eradication; natural and cultural environment; community environment; environmental education and promotion; and environmental technology. The policy with respect to pollution under the prospective plan is presented in Box 6.3.

Under the prospective plan, the Environmental Quality Management Plan (EQMP) (1999-2006) was established to outline the work plan for government agencies, state enterprises and relevant parts of the private sector, as well as indicating the implementation of environmental conservation at the provincial level (ONEP, 1997a). The environmental management framework (EMF) for 1999-2006 is presented in Box 6.4. The general pollution policy as part of the prospective plan did not mention AQM specifically. Air pollution was, however, considered as one of environmental problems in the EQMP. At a national level, PCD is responsible for formulating national policy and plans to enhance environmental quality (Section 6.3.4). Furthermore, government organisations at a provincial level are required to establish their environmental action plans within the framework established under the management plan. Moreover, the implementation of environmental management (EM) emphasises the prevention and control of the causes of environmental degradation (reduce pollution at source). Government agencies at the provincial level are required to set up EM plans as part of their annual budget framework and the prospective plan is used as investment guidelines for initiating development projects (ONEP, 1997a).

Box 6.3 The policy on environmental pollution under the Policy and Perspective Plan for Enhancement and Conservation of National Environmental Quality (1997-2016)

The Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality (1997 – 2016)

Policy on Pollution

1) Mitigate and control pollution from communities, agriculture, industry, transportation, and construction, such that they do not cause impacts to health and human living conditions; rehabilitate environmental quality in areas that have potential for economic development, for the ecological balance of natural resources and the environment in these areas, and to ensure sustainable development.
2) Provide systematic and effective wastes and hazardous material management; and establish protection and mitigation systems in cases of large scale emergencies.
3) Develop unified systems for administration and management of pollution and for formulation of pollution control policies, plans and implementation guidelines, under appropriate laws, institutions, and budgets, following the polluter pays principle. In addition, the private sector should participate in pollution control investments. The government, private sector, and local people, should work in cooperation.

Source: ONEP (1997b)

Box 6.4 The environmental management framework under the Environmental Quality Management Plan (1999-2006)

The Environmental Quality Management Plan (1999-2006)

Environmental Management Framework

1) To accelerate the solution of the problems of degradation of soil, land use, forests, water, mineral, energy, marine and coastal natural resources and the quality of water, air, noise, waste, toxic waste and hazardous waste, as well as to rehabilitate natural and cultural environments and the community. It aims to raise the environmental awareness of the public and use technology for the conservation of the environment.
2) Reform government agencies which manage natural resources and improve the networks between relevant government agencies in order to improve their efficiency and effectiveness.
3) Reform and improve outdated laws, regulations and rules which obstruct the conservation and sustainable development of natural resources and the environment.
4) Improve public attitudes and awareness towards the conservation of the environment by changing unsustainable practices and habits.

Source: ONEP (1997a)

In accordance with the EMF, the reformation of government departments has taken place. The Ministry of Natural Resources and Environment (MONRE) was established and departments that have major responsibilities covering environmental pollution and conservation of natural resources were placed under MONRE [such as PCD, ONEP, DEQP (see Section 1.5.1.1), Royal Forest Department, Department of National Park, Wildlife and Plan Conservation] (OPS, 2004). This reformation was intended to reduce bureaucratic red tape in the management of natural resources and the environment among the departments responsible in different ministries. However, EMF did not include a plan to assist local government organizations to develop their EM plans, for example, by capacity building schemes and technology transfer from central to local government organization. The lack of EM capacity (e.g. LAQM), was evident among SM and SAO officials in Chiang Mai (Section 6.4). On its own, the decentralisation of power and authority, from central to local government, may not be adequate to resolve environmental problems at a local level without technical and budgetary assistance. In addition, ONEP (1997a) recommended that the decentralization of competent officials (e.g. environmental scientists) is necessary in order to assist local government staff who may not have adequate environmental management expertise. ONEP (2002) admitted that the practice of decentralization of environmental management authority has not proceeded as expected, partly due to limited knowledge and experience at a local level. Sopchokchai (2001) stated that SAOs often undertake development projects without technical advice and coordination from central government agencies. Therefore, most of the development projects involve infrastructure such as village roads, small bridges and water supply systems that require minimal (simple) technology. Development initiatives that require specialist knowledge such as LAQM are rarely included in the annual SAO budgets for development projects.

Furthermore, it was found that local people did not fully participate in the decision making processes in development projects (ONEP, 2002). Sopchokchai (2001) also commented that although the Tambol (Sub-district) Administration Organization Act (1994) emphasises the participation of local people in planning and decision making processes, very few SAOs follow these regulations. Local residents are mostly unaware that they have this participatory right. However, MONRE attempted to resolve this problem by drafting regulations covering public participation for a new Environmental Act. As of May 2006, this act has not been enacted. The Ministry needs to establish an effective system to transfer national environmental policy and plans to the local level. This is because local government organisations find the policy and plans difficult to comprehend and implement [Thailand Environment Institute (TEI), 2003].

6.3.4 The Pollution Prevention and Mitigation Policy

Following the prospective plan, PCD included implementation guidelines for air pollution control to the Pollution Prevention and Mitigation Policy (PPMP) (1997-2016) (Box 6.5).

Box 6.5 Implementation guidelines for air pollution control under the Pollution Prevention and Mitigation Policy

The Pollution Prevention and Mitigation Policy (1997 – 2016)

Management guidelines

1) Separate industrial zones from communities and residential areas by implementing master city plans and prepare reports on the efficiency systems or facilities and equipment for controlling designated air pollutants emissions from industries.
2) Establish buffer zones around industrial estates and industrial zones in order to reduce air pollution impacts.
3) Continuously monitor, check, analyse and database the overall ambient air quality and emission of air pollutants from all sources.
4) Formulate prevention measures and prepare emergency plans for protection, mitigation, suppression or abatement of emergency situations or accidents from air pollution in local areas.
5) Assign local government agencies to prepare master plans and action plans for continuous reduction of air pollution in local areas.
6) Promote collaboration among government agencies, state enterprises and the private sector to control and prevent air pollution, and support efficient energy utilization.
7) Control and reduce utilization of substances that damage the ozone layer.
8) Promote investment in activities, facilities or equipment that mitigate and prevent air pollution.

Investment guidelines

1) Promote and support improvement and upgrading of fuels to meet international standards.
2) Support construction of efficient mass transit systems in large urban areas and between cities; construction of rail systems; and building and improvement of road and expressway systems in order to increase surface area available to traffic.
3) Upgrade roads passing through all rural villages, and seal entrance-exit roads (asphalt or concrete) up to approximately 1,000 m beyond village boundaries. Support local communities in developing efficient road cleaning programmes.

Legal guidelines

1) Formulate and improve air quality standards (both overall standards and emission standards) including designation of methods to check and measure pollution, in line with international standards, and strictly enforce these laws against offenders.
2) Establish categories of air pollution and odour sources that must be controlled, including formulation of appropriate standards.
3) Designate that all categories and ages of vehicles are to undertake annual inspections of fuel combustion discharge, using an inspection system based on the service centre model. Use the symbol 'Use forbidden temporarily' or 'Use forbidden absolutely' for polluting vehicles.
4) Formulate orders and regulations designating standard criteria and guidelines for practice to control construction and related activities, including the construction of roads that must be paved with a shoulder and a curb.

Supporting guidelines

1) Support and collaborate with the private sector, associations, independent groups and all categories of mass media to participate in public relations efforts and campaigns to educate and increase understanding and awareness of hazardous threats from air pollutants, and to inform of law enforcement actions against polluters.
2) Support study, research and training in technologies for air pollution control including improvement and maintenance of machinery to decrease pollutant emissions.
3) Promote the use of economic incentives to encourage solutions to the problem of air pollution reduction.

Source: PCD (1997b)

The following policy objectives for air pollution control were established in order to manage air quality within the national standards:

- Accelerate the reduction of air pollution from vehicles, industry, construction and transport.
- Maintain air quality in areas where air pollutant concentrations are below the standards.
- Promote and support the utilization of low pollution transport systems.
- Promote participation within the government, private sector and the public for managing air quality.

However, the following important aspects of the management guidelines have yet to be properly addressed:

- The establishment of industrial buffer zones should be a crucial aspect of the construction approval process as part of EIA by ONEP. Coordination among PCD, ONEP, DPT and their provincial offices is needed for the application of consistent regulations regarding the establishment of buffer zones, not only for major industrial estates but also for polluting factories outside the industrial zones that are located in residential areas.
- At the time of writing, PCD has not yet developed an up-to-date national emissions inventory for different sources of air pollutants as per item 3 in the management guidelines. The compilation of an emissions inventory has focused only on some areas such as Bangkok Metropolitan (as part of DIESEL project in 2004, see Section 5.6.5) and Chiang Mai Municipality (as part of the MDE study in 2001, see Section 2.2.1).
- The questionnaire survey conducted as part of this PhD project showed that AQM, including contingency planning, was not included in environmental planning by many local government organizations in Chiang Mai.

In addition, investment guidelines have not been established using a holistic approach to LAQM for local government organizations. ONEP focuses only on investment in road construction for villages without considering the control of other sources of air pollution such as forest fires and burning of agricultural and domestic wastes, which are major problems in the rural areas of Chiang Mai. In following the guidelines, SMs and SAOs may spend considerable amounts of their annual budgets on the construction of more roads as part of their air pollution abatement plans. In response to inadequate knowledge among local officials, the investment guidelines should also suggest that SMs and SAOs invest in the development of human resources such as, setting up capacity building courses (e.g. AQM) for their officials. In the longer term, it may be worthwhile to invest in the employment of environmental scientists or engineers to work for their organizations.

With respect to legal aspects, there are environmental laws, regulations and standards, but a lack of effective enforcement makes sustainable LAQM impossible (see Section 5.6.2). PCD should set clear guidelines to improve law enforcement systems as well as to introduce impartial enforcement to all provinces; not only Bangkok. For example, in 2004, PCD collaborated with the Traffic Police Department and other responsible agencies to conduct diesel vehicle inspection in Bangkok. As a result of the programme, approximately 8,000 diesel vehicles emitting black smoke, including public buses, were banned from operation (PCD, 2005). Such programmes should operate in other major cites such as Chiang Mai. In conclusion, with respect to air pollution control, the PPMP lacks of a holistic approach in support of the decentralisation of AQM to local government organisations.

6.3.5 Environmental Education in Thailand

The 9th NESDP also requires the reorganisation of the educational system, in order to better develop human resources in science and technology. More and better science study courses are needed for the effective application and development of appropriate technology (NESDB, 2001). The structure of education in Thailand covers formal and non-formal education. Formal education is conducted by educational institutes at 4 levels, namely pre-primary (for children aged 3-5 years), primary (6-8), secondary [lower secondary (12-14) and higher secondary (15-17)], and higher education (>17 years). In addition, informal education or lifelong education is provided to those missing the opportunity to have a formal education and there is no age restraint for learners in this category. Since January 2003, lower secondary education has been compulsory in Thailand (UNESCO, 2000). Since 1978, environmental education (EE) has been included in the Thai curricula for primary and lower secondary levels (Anunthavorasakul, 2004). It was introduced at the higher secondary level in 1981 and integrated within the science and social studies curricula. Topics included are natural systems, environmental problems, and environmental protection. In 1990, the national curriculum at each educational level was revised. EE became an elective subject at secondary level under the topic Science and Social Studies (e.g. Energy and Environment; Environmental Sciences) and it remained as part of the Life

Experiences subject within the primary level curriculum. The objectives/expected learning outcomes of the environmental curricula are that students should understand the benefits and practices of natural resource preservation; the relationship between humans and the environment; the consequences of environmental changes; the effects of the environment and biosphere on humans, plants and animals; and environmental protection (Anunthavorasakul, 2004).

Under the Education Act B.E. 2542 (1999), the national curriculum was again revised in 2001. EE is no longer separately specified, but is integrated into all subjects, especially sciences, social studies, religions and culture, and health education (Anunthavorasakul, 2004). In this way, schools have been given more freedom to develop their own curriculum using the core subjects as a framework. For example, they can develop subjects related to their local environment, pollution problems, and local experience. They are also able to construct a learning network and develop an EE curriculum with local communities, following the community-based education approach that is practiced worldwide.

The 9th NESDP briefly mentioned a policy to raise environmental awareness through the formal educational curriculum at all levels, in order to create appropriate attitudes to the conservation of natural resources, and the environment (e.g. the utilisation of environmentally friendly products and encouragement of participatory contribution to environmental management). However, specific strategic plans for operating and implementing the EE policy at a national level were not established. For example, the National Education Plan (2002-2016) of the Ministry of Education did not emphasise EE in the 15-year plan for Thailand [Office of the National Education Commission (ONEC), 2002], whereas EE is on of the main programmes of the Department of Environmental Quality Promotion (DEQP) under MONRE. This shows a lack of coordination and integration of national plans between the two ministries.

ONEP (1997b) reported that, although EE in Thailand is included in both formal and informal educational programmes, there is still a lack of local participation and consistency of content between educational levels and appropriate EE activities. Due to the lack of an effective environmental information network among government agencies and other stakeholders, the government's EE programmes have often not been relevant to local environmental problems. However, DEQP attempted to integrate EE into local agenda by establishing the Environmental Provincial Educational Centre (EPEC) programme (DEQP, 2006). Through this programme, DEQP promotes human resource development; for example, educators, teachers, community leaders and local government officials are trained in EE from concept to teaching skills (e.g. EE curriculum development) in both formal and non-formal systems. It also promotes networking between educational institutes and communities. DEQP provides not only technical support but also financial support to local educational institutes for EE initiatives appropriate to local environmental situations. In 2005, there were 59 EPECs in all regions of Thailand with 3 centres located in Chiang Mai Province. However, before more EPECs are established, DEQP should assess whether their previous EE programmes have been effective and are sustainable at a local level, and whether EPECs can operate effectively without technical and financial support from central government.

6.4 Air Quality Management at the Provincial Level in Chiang Mai

The Government, led by Dr. Thaksin Shinawatra, the Prime Minister of Thailand, attempted to resolve problems of bureaucracy by running the country using a top-down strategic approach to policy management. The Chief Executive Officer (CEO) Governor programme, established since 1 October 2001, is a holistic administration system designed to allow provinces to be managed more efficiently, effectively and strategically – similar to corporate business units (Youngsuksathaporn, 2005). The CEO Governors are expected to have ultimate executive responsibility or authority within their provinces. Not only are they expected to have a holistic vision and the capability to run their provinces strategically, but they are also required to manage the annual budget allocated to the provinces by the different ministries.

The Royal Thai Government allocates funds annually to each province to conduct a range of development projects. Theoretically, the projects that each province proposes for fund allocation should follow the NESDP. In Chiang Mai, under the CEO Governor programme, annual funds are allocated to government organisations that are responsible for development projects. Budget allocations for development projects in Chiang Mai Province in 2004 and 2005 are summarised in Table 6.2 and 6.3. The Provincial Executive Board, comprising Heads of Government Agencies in the province, initially discuss the suitability of projects with the government departments responsible for them; then these are approved by the CEO Governor. For example, in Table 6.3, the project *Expansion of Forestry Area and Environmental Management in Communities* is being conducted by the Chiang Mai Office of Natural Resources and Environment; and the project *Technology*

Promotion of Treatment of Wastewater from Dyeing Processes is the responsibility of the Industrial Promotion Centre.

Table 6.2 Budget allocation for development projects in Chiang Mai Province in 2004

Project	Budget in US$*	%
1. Promotion of international relations (Chiang Mai as Sister City)	$50,000	5.8
2. Promotion and development of trade and investment among the countries in the Greater Mekong Sub-region (GMS) and BIMST-EC** countries	$50,000	5.8
3. Study of investment channel	$25,000	2.9
4. Establishment of geographical information system for trade and investment	$61,287.5	7.1
5. Promotion and development of the International Organization for Standardisation (ISO) standards in business sector	$47,372.5	5.5
6. Capacity building of health service sector	$12,500	1.5
7. Promotion of Chiang Mai Brand products	$43,485	5.0
8. Chiang Mai Beautiful City Project ('Chiang Mai Muang Ngam')	$109,965	12.7
9. International Professional Sport Competition	$25,000	2.9
10. Creation of Chiang Mai image for tourism and public relations	$25,000	2.9
11. Development and improvement of the Hilltribe Museum	$14,625	1.7
12. Promotion of the International Standard Organization (ISO) standards in health service sector	$7,500	0.9
13. Teaching programme for basic English conversation for people in tourism industry	$12,500	1.5
14. Capacity building in business for Thai 'longan' fruit	$125,000	14.5
15. Promotion of the plantation of economic fruits and vegetables for export and reduction of import	$137280	15.9
16. Establishment of a learning centre of local cultures and wisdoms in community	$3,000	0.4
17. Development of highland community for restoration of forests, and promotion of community forest	$12,500	1.5
18. Expansion of 'green' areas and parks	$12,500	1.5
19. Development of marketers	$46,750	5.4
20. Development of Chiang Mai chefs and cooks for world's kitchens	$27,000	3.1
21. Promotion of craftsmanship for international standards	$14,875	1.7
Total	**$863,140**	**100**

Note: *40 Thai baht = 1 US dollar. **BIMST-EC is Bangladesh-India-Mynmar-Sri Lanka- Thailand Economic Co-operation. Bhutan and Nepal are also BIMST-EC members. The underlined projects are directly related to improving environmental quality in Chiang Mai. **Source:** Chiang Mai Provincial Office (2003)

In 2005, other air pollution related projects that fall outside the CEO Governor Programme include the project *Air Quality Management in Chiang Mai and Lamphun Provinces* (US$10.63m) (see Table 6.4); and the formation of a Committee for Resolving Dust, Air, and Noise Pollution in Chiang Mai (CRANC) (since 1 September 2004) The latter project is led by the Chiang Mai Governor, and involves 18 representatives from different government agencies in the province (e.g. PONRE; CMOPT; PAO; CMM; Provincial Agricultural Extension Office; Provincial Police; Office of Public Health; Provincial Industry Office (CRANC, 2005). CRANC also established the Air Pollution Emergency Call Centre on 3rd March 2005 (see Section 5.6 (iv)). The Call Centre, managed by the

Director of Environment Office (Region 1), utilises resources drawn from both the government and the private sectors including media (e.g. Chiang Mai Radio and TV Club and Northern Newspaper Club).

Table 6.3 Budget allocation for development projects in Chiang Mai Province in 2005

Project	Budget in US$*	%
1. Promotion and development of trade and investment among the countries in the Greater Mekong Sub-region (GMS) and BIMST-EC countries	$75,000	3.3
2. Promotion of small and medium enterprises (SMEs)	$50,000	2.2
3. Capacity building of marketing and business in health service sector	$63,825	2.8
4. Development of 3 handicraft communities for tourism	$150,000	6.5
5. Development and improvement of conservative tourist attractions	$225,000	9.8
6. Standard elevation of Wieng Kum Kam ancient village	$25,000	1.1
7. Chiang Mai Fashion City (Lanna Style)	$50,000	2.2
8. Development of One Tambon One Product (OTOP) products and packaging	$50,000	2.2
9. Promotion of agricultural products (transformation)	$25,000	1.1
10. Organic fruit and vegetables	$25,000	1.1
<u>11. Promotion of organic fertiliser for safe agricultural practices</u>	$15,000	0.7
<u>12. Forest preservation and forest fire prevention (workshop programmes and construction of small dams for agricultural purposes) (King's initiative)</u>	$75,000	3.3
13. Programme for English and Chinese learning for tourism industry	$15,569	0.7
14. Conservation of Lanna culture	$30,000	1.3
15. Information and Communication Technology (ICT) training programme	$50,000	2.2
16. Alleviation of poverty (Integration approach)	$125,000	5.4
17. Chiang Mai Beautiful City Project ('Chiang Mai Muang Ngam')	$200,000	8.7
18. Establishment of Strategy Operation Centre (War Room) and development of Information and Communication Technology (ICT)	$150,000	6.5
19. Human resource development and capacity building in silver industry	$50,000	2.2
<u>20. Expansion of forestry area and environmental management in communities</u>	$41,450	1.8
<u>21. Technology promotion of treatment of wastewater from dyeing process</u>	$12,500	0.5
22. Promotion of strategic plans for development of Chiang Mai province	$132,500	5.8
23. Development of historical places for tourism	$100,000	4.3
24. Capacity building of competitive tourism industry	$7,500	0.3
25. Mountain bike tournament for promotion of off-season tourism	$12,500	0.5
26. Training of safe agricultural products	$37,500	1.6
27. Elevation of security standard by using CCTV	$125,000	5.4
28. Capacity building of Thai fabric in Lanna-styled fashion	$99,000	4.3
29. Promotion of Chiang Mai Brand products	$52,450	2.3
30. Promotion of Chiang Mai fruits	$25,000	1.1
31. Town planning and landscape improvement in Wat Ket area	$194,031	8.4
32. Promotion of Chiang Mai province (Past, Present and Future of Chiang Mai) by using media	$11,175	0.5
Total	**$2,300,000**	**100**

Note: *40 Thai baht = 1 US dollar. The underlined projects directly address issues related to improving environmental quality. **Source:** Chiang Mai Provincial Office (2003)

On the basis of the above evidence, it is suggested that air pollution has not been given any significant priority by the Provincial Office of Chiang Mai. In 2004, of the 21 funded projects, only two were directly related to the environment (*Development of Highland Community for Restoration of Forests and Promotion of Community Forests*; and *Expansion of 'Green' Areas and Parks)*. Moreover, these two projects only accounted for 1.5% of the total budget of THB34,525,600 (US$863,140) (Table 6.2) and neither was concerned with air quality management.

In 2005, the situation had improved and the funds allocated to environment-related projects accounted for approximately 5.3% of the total budget (THB92,000,000 or US$2,300,000) (Table 6.3). There were 4 environment related projects approved: *Promotion of Organic Fertiliser for Safe Agricultural Practices; Forest Preservation and Forest Fire Prevention; Expansion of Forestry Area and Environmental Management in Communities; Technology Promotion of Treatment of Wastewater from Dyeing Processes*. The project *Forest Preservation and Forest Fire Prevention* was allocated the largest budget (THB3,000,000 or US$75,000) and the second largest amount went to the project *Expansion of Forestry Area and Environmental Management in Communities* (THB1,658,000 or US$41,450). However, again no project directly addressed issues related to air pollution control.

Although it is seen as such, the Air Pollution Emergency Call Centre does not provide the best and only solution for solving air pollution from burning of wastes. This problem will not be resolved until an effective system of waste collection and disposal is set up for the province – not only for the Chiang Mai Municipality areas. Furthermore, the development of landfills has not received the attention given to other basic infrastructures (e.g. roads, electricity and tap water). However, urban planning and civil works in Chiang Mai must include the development of landfill sites, and a waste collection, recycling and disposal network, if uncontrolled waste burning is to be eliminated.

To address domestic waste problems, the SEPCO Holding Co. Ltd. (UK) has introduced sophisticated technology to resolve waste management problems and introduce renewable energy to Chiang Mai. The THB1.1 billion project *Turning Garbage to Energy* was launched under a Memorandum of Understanding (MOU) for co-operation between the British and Thai Governments. The technology involves two main processes: i) steaming domestic wastes under high pressure (75psi) and temperature (> 160 °C), and drying to produce powdered organic wastes; ii) producing energy from powdered organic wastes and lignite mixtures by burning at power stations. During the first process, plastics and glass are melted and reduced in volume for recycling. Two facilities, each having a capacity of 200 tons of domestic wastes per day, are being installed at Hai Ya Cemetery, Muang district. The factory was intended to operate in 2006. It is anticipated that this project will help to manage approximately 280 tons per day of domestic wastes produced within CMM areas. When full operation starts, it is anticipated that the cost of waste disposal will be reduced from THB590 per ton (using landfills of private companies) to THB300 per ton (Krailerg, 2004). Politically, this project is attractive to local residents who resist the development of landfill sites. However, this project may solve illegal waste burning problems only in Muang district. The cost of the technology is unaffordable for other local government organizations. Alternative waste management systems are needed urgently to resolve domestic waste burning problems in Chiang Mai. Some measures are recommended in Chapter 7.

Another project, *Air Quality Management in Chiang Mai and Lamphun Provinces* attempted to tackle air pollution in those areas. Of the total budget of THB425.05m (US$10.63m), the highest percentage was allocated to tackle air pollution in Chiang Mai province (approximately 69%) and the remaining (31%) was allocated to Lamphun (Table 6.4). In Chiang Mai, the five main activities of the project are: abatement of air pollution from traffic sources (60.7% of total funds for Chiang Mai); the control of open waste burning (20.1%); air pollution control at construction and other miscellaneous sites (0.1%); landscape improvement in Muang (City) district (13.7%); building up efficacy of air quality management (5.4%) (Figure 6.1).The largest proportion of the funding was allocated to the abatement of traffic related pollution. The project is conducting a feasibility study and designing a mass transport system (an electric railway system) in Muang district, for THB145m (US$3.6m). The management of this task is the responsibility of the Office of Transport and Traffic Policy and Planning.

Table 6.4 Activities and budget allocation details for the project Air Quality Management in Chiang Mai and Lamphun Provinces

Strategy/Activity for Chiang Mai	**Budget Million THB/US$***
1. Pollution abatement from Traffic sources	
1.1 Improvement of mass transport	
- Improvement of transport routes for minibuses (24 minibuses on 3 routes)	-
- Setting up 2 routes for school bus system	-
- Setting up more routes for 'songtaew' and promotion of the use of minibuses for transport in Muang (City) District	-
- Conducting a feasibility study and designing a mass transport system in Chiang Mai (Muang (City) District)	145.0/3.625
1.2 Campaign for the use of bicycles	
- Improvement and construction of bike lanes in the moat area in city centre (CM Municipality)	14.0/0.35 6.4/0.16
1.3 Promotion of the use of bio-diesel in 'songtaew'	-
1.4 Control of black smoke vehicles	0.97/0.025
- Exhaust inspection service team	7.0/0.175
- Purchase equipment for black smoke and noise inspection	2.4/0.06
- Purchase vehicles for black smoke inspection programme	1.5/0.0375
1.5 Raising public awareness in air pollution abatement from motor vehicles	
Sub total	**177.27/4.43**
2. Control of open burning	
2.1 Control of agricultural burning	
- Promotion of ploughing technology for rice stalks	3.0/0.075
- Promotion of ploughing for rice stalks together with the use of organic fertiliser (liquid effective micro-organism); training farmers; demonstration plots	9.43/0.236
- Conversion of domestic wastes to fertiliser	-
2.2 Control of domestic waste burning in community	-
- Set up regulations to control domestic waste burning	-
- Monitoring and inspection	-
- Effectively collect and dispose domestic wastes	-
- Promotion of composting in household and community level	-
2.3 Control of forest fires	46.31/1.158
Sub total	**58.74/1.47**
3. Air pollution control from other sources	
3.1 Control of dust from construction sites	-
3.2 Control of emissions from industries (in Muang district), hotels, hospitals, petrol stations	0.22/0.006
Sub total	**0.22/0.006**
4. Improvement of landscape in Muang district	
4.1 Road clean-up	
- Purchase 2 road vacuum cleaners for Chiang Mai Municipality	20/0.5
4.2 Expansion of 'green' areas	20/0.5
Sub total	**40/1.0**
5. Building up efficacy of air quality management	
5.1 Air quality monitoring	
- Continuous monitoring of air quality (2 existing automatic air monitoring stations)	2.0/0.05
- Setting up digitalised monitor for reporting air quality data	1.0/0.025
- Other air pollutant monitoring	2.7/0.068
5.2 Campaigning, public relations, and public participation in Chiang Mai and Lamphun	
- Capacity building (air quality management) for staff of the Environment Office (Region 1); Provincial Office of Natural Resources and Environment; Local Administration Offices; public relations using media (radio, TV and newspapers); produce publications for the young and general people; campaign for the bicycle use.	10.0/0.25
Sub total	**15.7/0.393**
Total	**291.93/7.30**

Note: Total project cost is THB425.05million (THB291.93m allocated to Chiang Mai province and THB133.12m allocated to Lamphun province). *40 Thai baht = 1 US dollar.

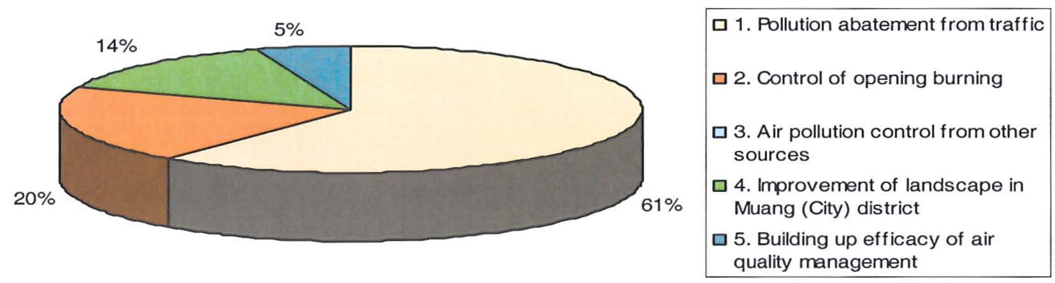


Figure 6.1 Percentage of Chiang Mai Province environmental project budget (2004) allocated to different air pollution abatement and air quality management measures

However, it is not certain if the project tasks described above represent good value for money since project implementation is restricted to one district only. The responsible government agencies in Chiang Mai should also use the results of previous road traffic related studies, such as, *the Study on Improvement of Road Traffic Environment in Chiang Mai City (2002)*, financially supported by the Japan International Cooperation Agency (JICA) (JICA, 2002) (hereinafter referred to as 'the 'JICA Study'). Its objectives were: to formulate road traffic environment improvement plans for alleviating traffic congestion, and for securing road safety in Chiang Mai Municipality area (approximately $60km^2$); and to implement technology transfer to the Thai counterparts [Royal Thai Police (RTP) and CMM)] through a seminar and informal workshop. The following findings and recommendations of this study are considered important for transport management in Chiang Mai. This study provided useful data with respect to traffic management in Chiang Mai (i.e. estimated traffic volume in 2010; congestion prone road sections and intersections; identified traffic management problems; identified the demand profile for public transport within the CMM area, and between CMM and outer districts). This information can be used for improving the traffic system in Chiang Mai.

It follows from the above that there is no lack of information regarding traffic and public transport management in CMM. Public transport vehicles are also available: the Northern Citizen, a local newspaper (vol. 169, 21 – 27 February 2005) revealed that CMM recently purchased 26 air-conditioned minibuses (total cost THB62million). Originally, these could not be officially operated for public service mainly because of protests from the Nakorn Lanna Transportation Co-operatives, which represents 'songtaew' operators (Figure 6.2). However, the problem was assumed to be resolved by a team that consisted of different government agencies led by the Governor. Three bus routes (within Muang District) for the Chiang Mai Bus (CMB) services were approved by the Chiang Mai Office of Land Transportation. Originally, the CMB was planned to operate on 1 July 2005 on only 2 routes, mainly in the city centre, due to insufficient buses. Nevertheless, 'songtaew' operators protested the CMB routes and the buses were unable to operate, as planned. To avoid further conflict the CMM has investigated alternative routes. Finally, CMB started services in November 2005 (pers. comm. Mr. Panyapol Mongkolchareon). At present, 'songtaews' still provide the majority of public transport, partly due to insufficient CMB buses. CMM should investigate how to operate CMB in a cost-effective way to better satisfy transport demand in the long term.

Photographed by K. Sriyaraj

Figure 6.2 A typical 'songtaew' (modified pick-up truck) used for non-fixed route, public transport

It might be concluded that there is no need to spend THB145m (US$3.6m) to conduct another feasibility study and to produce another design for a railway system in the CMM area. Instead, the government could have used the money for implementation. The priority regarding mass/public transport in Chiang Mai must be to review the strategy of the major concessionaire of most transport routes in Chiang Mai (the Nakorn Lanna Transportation Co-operatives) and address the problems faced by Chiang Mai people and tourists who are forced to continue to use the ineffective non-fixed route public transport services provided by the 'songtaews'. Additionally, the expansion of CMB routes to gradually replace old 'songtaew' vehicles must be considered as an alternative action to the design of an electric railway system which can generally only serve passengers who are tourists to Chiang Mai's Night Safari Park. It may be more appropriate for Chiang Mai to spend THB145m on the purchase of more LPG buses and to expand the CMB routes to serve local people in other parts of Muang District and the outer urban districts of the province.

In contrast, the project *Building up Efficacy of Air Quality Management (AQM)* received only THB15.7m (US$0.39m). This project is about implementation and comprises 2 main tasks – air quality monitoring; and campaigning, public relations, and public participation, including capacity building for local government staff. However, it fails to address other key AQM aspects (see Section 5.5.2) (e.g. development and annual update of an emissions inventory; air quality modelling; public consultation; regular distribution of air quality information; promotion of good urban governance, improvement of indoor air quality).

6.5 Results and Discussion – Vision and Capacity of Environmental Management at a Local Level in Chiang Mai

Seventy-eight per cent of the distributed questionnaires were returned. All returned questionnaires were included in the review, although, some were not fully completed. Most conspicuously, answers to questions 4 and 5 frequently remained unanswered. This may be due either to a lack of complete information regarding environmental plans and policies in sub-districts, or to a lack of knowledge of topics that are not of their concern or direct responsibility. The results of the questionnaire survey are summarised in Table 6.5.

The purpose of the opening question (Question i) was to remind the respondents that the strategic development plans typically consist of 6 topics – basic infrastructure, human resources and society, local economic conditions, education, religion and tradition, water resource, and natural resources and environment (Table 6.5). Figure 6.3 illustrates the comparison between the respondents at the executive and operational levels. In comparison to the executive level, the respondents at the operational level gave a lower percentage of positive answers to all the 6 priorities under the strategic plans of their organisation, particularly the development of local economic conditions (85.7% vs. 56.4%), and natural resources and environment (81.0% vs. 64.1%). Basic infrastructure development was given the highest priority at both executive and operational levels, accounting for 90.5% and 80.8% respectively.

Table 6.5 The results of the questionnaire survey investigating the vision of local government organisations in Chiang Mai regarding air quality management

Question	Executive level		Operational level		Total	
	$N^{\dagger}$	%	$N^{\ddagger}$	%	N^{*}	%
i) What are the priorities under the strategic plans of your organisation?						
a) Development of basic infrastructure	19	90.5	44	77.2	63	80.8
b) Development of human resources and society	16	76.2	35	61.4	51	65.4
c) Improvement of local economic conditions	18	85.7	26	45.6	44	56.4
d) Development of education, religion and tradition	14	66.7	32	56.1	46	59.0
e) Water resource development	16	76.2	35	61.4	51	65.4
f) Improvement of natural resources and environment	17	81.0	33	57.9	50	64.1
g) Others	0	0.0	0	0.0	0	0.0
ii) What are the major environmental problems in your responsible areas?						
a) Solid wastes	12	57.1	34	59.7	46	59.0
b) Water pollution	8	38.1	20	35.1	28	35.9
c) Air pollution	5	23.8	18	31.6	23	29.5
d) Odour from animal farms	4	19.1	11	19.3	15	19.2
e) Forest fires	6	28.6	10	17.5	16	20.5
f) Deforestation	3	14.3	2	3.5	5	6.4
g) Chemicals/pesticides used in agriculture and industry	5	23.8	6	10.5	11	14.1
h) Noise pollution	2	9.5	2	3.5	4	5.1
iii) What environmental projects were undertaken in your areas of responsibility in the past few years?						
a) Water resource management	13	61.9	19	33.3	32	41.0
b) Air pollution abatement	9	42.9	19	33.3	28	35.9
c) Domestic waste management	17	81.0	30	52.6	47	60.3
d) Agriculture	16	76.2	24	42.1	40	51.3
e) Conservation of forest	13	61.9	30	52.6	43	55.1
f) Others	0	0.0	0	0.0	0	0.0
iv) Did your organisation include environmental management in the 3-year development plans (2005 – 2007)?						
a) Yes	15	71.4	24	42.1	39	50.0
b) No	1	4.8	2	3.5	3	3.8
c) Not answered	5	23.8	31	54.4	36	46.2
v) Do you expect that the environmental management plans in iv) will produce significant improvements within your area of responsibility?						
a) Yes	11	52.4	19	33.3	30	38.5
b) No	0	0	0	0	0	0
c) Not answered	10	47.6	38	66.7	48	61.5

Note: Total $N^{\dagger}$ (executive level) = 21; Total $N^{\ddagger}$ (operational level) = 57; Total N^{*}(both executive and operational level) = 78.

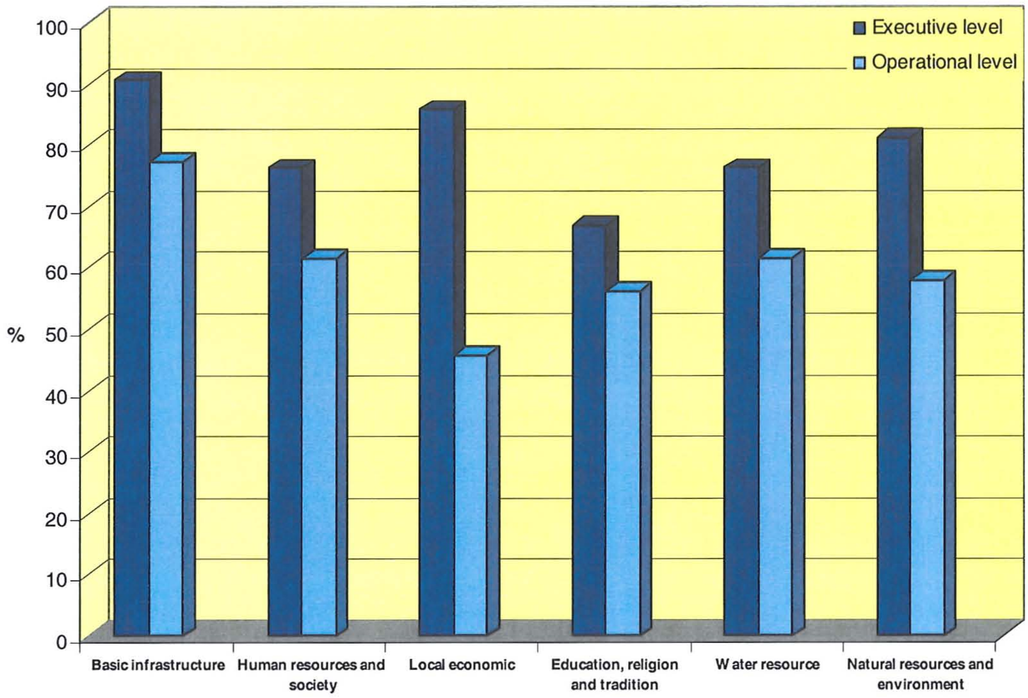


Figure 6.3 Summary of responses to Question i regarding the priorities under the strategic plans of SM/SAO organisations in Chiang Mai Province. It can be seen that operational level employees perceived fewer priorities than those at executive levels.

Answers to Question ii showed whether air pollution is considered a major cause of concern in the sub-districts (Figure 6.4). It was found that only 5 out of 21 (23.8%) executives identified air pollution as a problem in their sub-districts, whereas 18 out of 57 operational officers (31.6%) thought air pollution was important. Solid wastes were perceived to pose the most serious environmental problem by both executive and operational officers (57.1% and 59.7% respectively). However, executive officers were aware that an important cause of air pollution is the open burning of agricultural and domestic wastes. Only one CEO identified road traffic as a source of air pollution. It follows, that the main action undertaken to reduce air pollution was the issue of local notices that asked villagers not to burn wastes. According to the survey, only one SAO had educated villagers about air pollution from forest fires, road traffic, quarrying activities, and pesticide spraying. For future environmental management, none of them had explained about direct action plans to tackle air pollution (e.g. LAQM). At the operational level, 16 out of 57 respondents (28%) considered that air pollution, mainly from dust and smoke, presented an environmental problem in their sub-district. 32 of 57 (56.1%) associated domestic waste burning with 'dust and smoke'. 7 out of 57 (12.3%) cited road traffic as a cause of pollution (mainly 'dust'). Finally, only 4 out of 57 (7%) mentioned that industrial activities in their sub-districts cause air pollution.

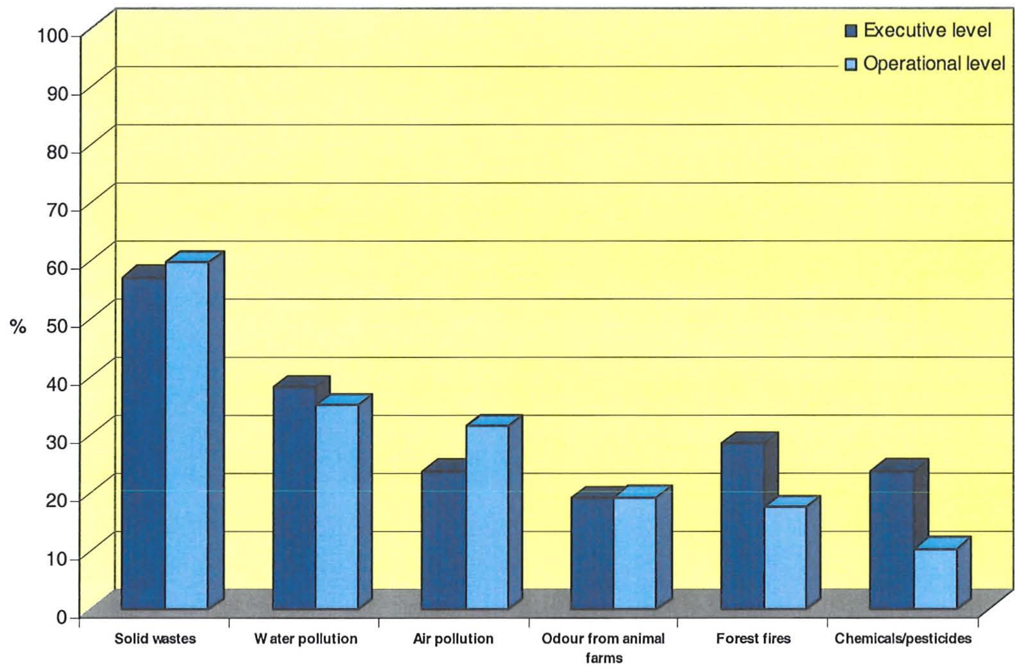


Figure 6.4 Summary of responses to Question ii regarding major environmental concerns of SM/SAO organizations in Chiang Mai Province

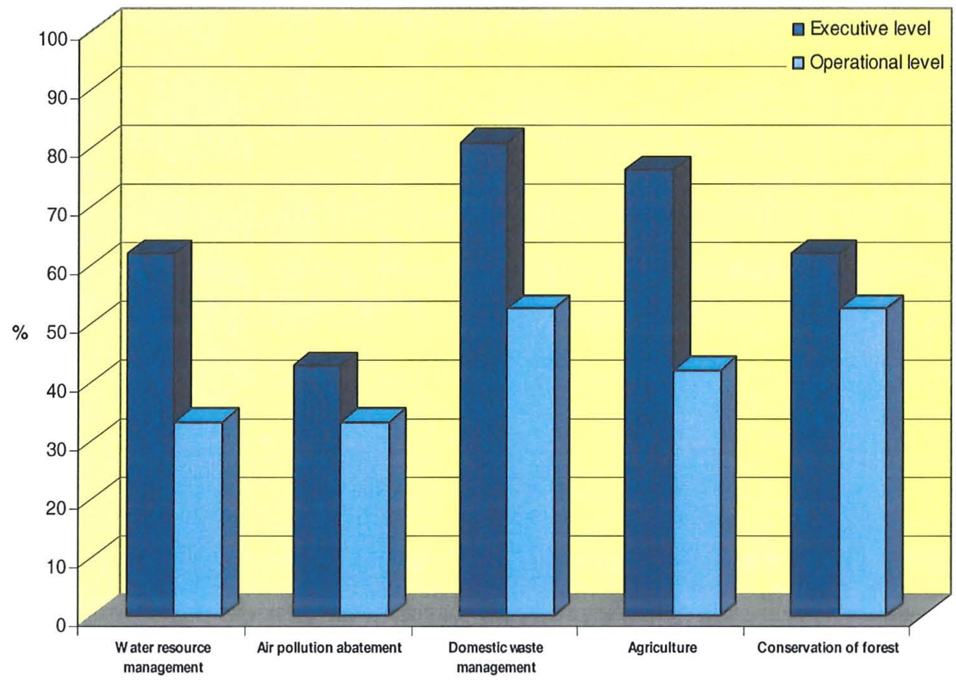


Figure 6.5 Summary of environmental projects undertaken in SM/SAO organisations within Chiang Mai Province

Figure 6.5 illustrates the recent environmental projects that were undertaken in the sub-district and municipality areas. It was seen that air pollution abatement projects were given the lowest priority at both executive and operational levels within local government organisations (42.9% and 33.3%, respectively). At the operational level, the highest priorities were given to projects relating to domestic waste management (81.0%), agriculture (76.2%) and domestic wastes (52.6%).

In response to Question iiic, 17 out of 57 (29.8%) replied that, in the past 2 – 3 years, a campaign, *via* local announcements and posters, was undertaken to prevent the burning of waste. However, only one respondent (1.8%) replied that his SAO educated the villagers about air pollution and undertook to persuade farmers not to burn agricultural wastes. It would seem that the main focus was to solve problems associated with domestic waste disposal and management. One SAO distributed a metal bin to each house for the disposal and burning of waste, highlighting either a lack of knowledge about or disregard for air pollution, air quality management and appropriate technology for waste management.

In response to question iv, approximately 50% of the questionnaire respondents reported that different environmental management (EM) programmes were included in their 3-year development plans (2005 – 2007) (Figure 6.6). Only 4% of all respondents gave a negative response to this question and 46% of them did not answer, which implied that either they did not know about the present environmental plans and policies of their organisations, or that an EM programme was not included in the development plans.

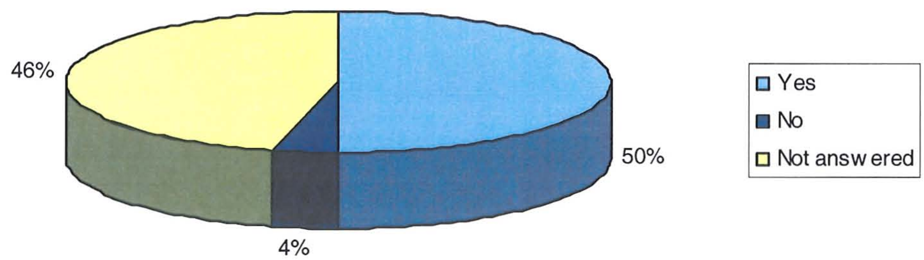


Figure 6.6 Pie chart illustrating whether environmental management was included in the 3-year development plans (2005 – 2007) of local government organisations in Chiang Mai Province

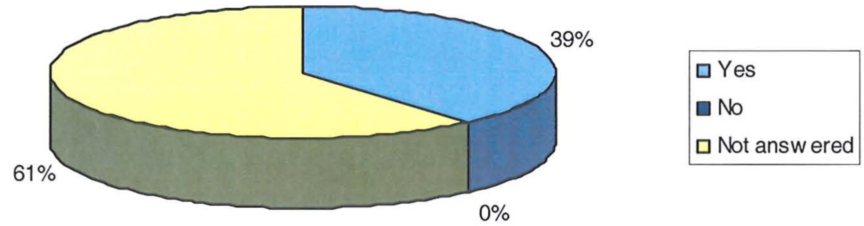


Figure 6.7 Pie chart illustrating the attitude of SM/SAO officials concerning whether the environmental management plans included in the 3-year development plans (2005 – 2007) would produce a significant change

In response to Question v, only 39% of all the respondents thought that the EM plans drafted in their 3-year development plans (2005 – 2007) would produce a significant change in their areas of responsibility, whereas the remainder, (61%), did not answer this question (Figure 6.7). This may be because they either did not know the details of their 3-year development plans or because they thought that the EM plan would not make any difference in their sub-districts.

In response to a final additional question, asking for comments and suggestions, 4 executive officers indicated that they wanted the Government to provide experts in the environmental management field to educate both their organisations and the local villagers. Also, a need for the Government to provide more funds for EM programmes was indicated. The respondents indicated a need for government organisations, responsible for environmental management to collaborate with SMs and SAOs - particularly during the drafting of environmental policies and plans, and when trying to enforce environmental laws. The view was expressed that the local organisations in Chiang Mai do not have enough capacity to resolve domestic waste problems, and that without external assistance from the Government, environmental problems will get out of control. Four respondents, representing operational officers, made a similar point about the annual funds allocated to their organisations and described them as insufficient to resolve environmental problems in their sub-districts. Finally, another respondent commented that lack of participation from regional and provincial government organisations allows the problems to worsen.

It is clear that current environment-related projects can alleviate, but not actually resolve, the problems. Therefore, there is an urgent need for holistic plans for action within each level of government administration (local, provincial and national). Public participation is also required. In addition, a major cause of the problems of SMs and SAOs is that officials at an executive level do not have the necessary knowledge and vision to produce and implement environmental management. The results of this questionnaire survey suggest that the Chiang Mai Governor's provincial policies have resulted in little action to improve air quality and that the only action undertaken was a campaign to persuade villagers not to burn any wastes. In the current situation, many villagers still burn wastes and the forest fire problem remains. It can be concluded that SMs and SAOs in Chiang Mai are not able and insufficiently resourced to develop and implement LAQM. In contrast, projects involving basic infrastructure such as roads, electricity and tap water that require simple and established technologies have been widely undertaken. Even so, waste collection and disposal systems (e.g. landfill and incinerator) are included in the future development plan because air pollution in Chiang Mai can no longer be ignored. The campaign to stop open burning in Chiang Mai is an immediate action taken at the provincial level. However, it is currently not clear whether LAQM is included in present and future development plans at the provincial level.

6.6 Conclusion

Air pollution problems have not been resolved in Chiang Mai Province, although some responsible organisations are aware of them. This is mainly because the Thai Government has not prioritised air quality management (AQM) at the national level. The National Economic and Social Development Board (NESDB) failed to specifically include the development of air quality management plans into the Natural Resources and Environment Management (NREM) of the 9th NESDP. In addition, the Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality did not provide a specific framework for AQM at the national, provincial and local levels. The PCD's Pollution Prevention and Mitigation Policy is also not supportive of the decentralization of environmental management to local governmental organizations particularly the Sub-district Administration Organisations (SAO) and Sub-district Municipalities (SM). At a national level, it seems that responsible planners and policy makers themselves do not take a holistic approach to environmental management and do not foresee the obstacles to decentralization, particularly AQM as well as local institutional problems. Local government organizations were not ready to implement the transferred decentralization mandates for the management of natural resources and the environment, due to lack of clear directives and frameworks in environmental planning (TEI, 2003). As a result, these organizations are unable to translate various policies into practice. Therefore, it is important to establish environmental policy and plans with clear and specific guidelines, frameworks and actions for them to implement.

Since air pollution is not seen as a principal cause for concern at the national level, there is little hope for improving air quality at both provincial and local levels. Also, there is no LAQM establishment required in the strategic Government Management Plan (GMP). Additionally, the only strategic plan directly related to air pollution abatement focuses mainly on mobile road sources (i.e., promote the use of cleaner fuels and low emission motor vehicles), and fails to address other air pollution sources. Furthermore, the 9th NESDP did not specifically outline, in its strategic plans, how to operate, develop and implement environmental education (EE) in Thailand – particularly at the local level. Nor did, the 25-year National Education Plan emphasise the importance of EE and it is unclear whether enough guidance has been provided to help develop the EE curriculum for schools in Thailand. However, the Environmental Provincial Educational Centres (EPEC) are a sound establishment for the promotion of EE at grassroots level throughout the country. The Government should provide more support for such programmes through the formal educational system as part of the National Education Plan.

Although there is a provincial AQM plan, including budgets for different activities, there are none involving SMs and SAOs. Responsible government organisations in Chiang Mai have not addressed all major sources of air pollution. As part of the CEO Governor programme, only a small percentage of annual funds was allocated to environment-related projects - mainly forest preservation in both 2004 and 2005. However, the establishment of the Committee for Resolving Dust, Air, and Noise Pollution in Chiang Mai (CRANC) is a sign of attempts to tackle air pollution in Chiang Mai, and did lead to the establishment of the Air Pollution Emergency Call Centre. This centre mainly receives reports and complaints from local people about illegal burning of domestic and agricultural wastes, but also includes forest fires. However, CRANC's areas of responsibility tend to cover only Chiang Mai Municipality areas. At a local level, SMs and SAOs in Chiang Mai are unable to conduct LAQM on their own because of a lack of technical capacity, budgets and personnel such as environmental scientists/engineers to work specifically on environmental projects. External assistance from responsible provincial organizations in Chiang Mai, as well as central government organizations, is crucial during the transitional phase of decentralization.

Furthermore, the campaign to stop open burning is an immediate action that needs to be taken in order to control air pollution at both local and provincial levels. The establishment of an alternative effective waste collection and disposal network is urgently needed for all areas in Chiang Mai Province.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS FOR SUSTAINABLE MEASURES TO IMPROVE AIR QUALITY IN CHIANG MAI

7.1 Conclusion

The research study *Local Air Quality Management and Health Impacts of Air Pollution in Chiang Mai, Thailand* was conducted during 2002-2005 in 5 parts: i) modelling air quality using ADMS-Urban model; ii) a questionnaire survey in urban and suburban areas to investigate residents' attitudes to air pollution and health; iii) a study of respiratory diseases and allergies among school children (ISAAC questionnaire study); iv) a comparison of urban air quality management (AQM) between Thailand and Hong Kong SAR, with respect to conformance with the principles of Good Urban Governance (GUG); v) investigation of current AQM policies and plans in Thailand. Figure 7.1 illustrates the methodology and results of each research component. The findings from these investigations and the limitations of the research methods used are summarised as follows;

7.1.1 Modelling Air Quality in Chiang Mai

ADMS-Urban was selected by the London Borough of Barnet (LBB) and Middlesex University (MU) for use in Chiang Mai as part of the EC Asia Urbs, MAQHUE project. However, when applied to Chiang Mai data, the model was found to have major technical limitations because it could not cope with the very low wind speeds and complex topography of the province. Other limitations were associated with the quality of input data and included the unavailability of an up-to-date emissions inventory, emission factors and background pollutant concentrations (see Section 2.2). Furthermore, ADMS-Urban is generally only applicable to micro-scale urban air modelling and does not easily cope with pollutant sources on larger scales. For instance, local air pollution in Chiang Mai may also be influenced by transboundary pollution at the regional or trans-national scales, but ADMS-Urban was not designed to work on this purpose.

However, ADMS-Urban was found to be useful in terms of predicting relative pollutant concentrations in different urban areas within Chiang Mai. The outputs of air modelling (i.e. the pollution maps indicating air pollution 'hot-spots') influenced the selection of air polluted sites for conducting the questionnaire surveys in parts (ii) and (iii) (Chapters 3 and 4).

7.1.2 Quality of Life Questionnaire Survey Conducted in Urban and Suburban Areas of Chiang Mai

As part of the MAQHUE project, a questionnaire survey was conducted in Chiang Mai using a Quality of Life (QoL) questionnaire (originally designed by Middlesex University for a survey in London Borough of Barnet) as a tool to investigate residents' attitudes to air pollution and health in urban and suburban areas of Chiang Mai. The questionnaire was modified (and translated into the Thai language) in order to suit Chiang Mai situations and Thai culture (see Section 3.2.1). The respondents were selected using a sampling judgment method and the survey was administered by personal interview. It was found that the modified Thai questionnaire was easy to comprehend and the personal interview enabled respondents to ask the interviewers for clarification where this was necessary. However, there were some uncertainties due to the sampling method used in this study as it may have introduced a selection bias (see Section 3.5). It was found that some relevant and potentially useful questions (e.g. occupation) were excluded from the modified questionnaire and some wording with respect to frequency may not have been appropriate. A validity test in a complete pilot survey would have overcome these problems.

The results showed that the urban respondents had a higher percentage of respiratory diseases than suburban respondents. The main sources of urban air pollution included traffic and domestic waste burning. Most of the respondents used either their own cars or motorcycles (40% and 36%, respectively). In comparison to suburban respondents, urban respondents had different opinions about air pollution. For example, approximately 70% of urban respondents replied that stress and air pollution were major factors affecting their health, whereas, suburban respondents focused on stress and poverty. Furthermore, approximately 87% of the respondents in both areas had never received air quality information and were very interested in obtaining this information. Television was selected by most of the respondents as the preferred media for the dissemination of air quality information.

7.1.3 The Prevalence of Respiratory Diseases and Allergies among School Children in Chiang Mai

In order to investigate the potential impacts of air pollution on respiratory health in children, the ISAAC questionnaire was circulated to the parents of children in 4 urban schools, and 2 rural schools. The results showed that the prevalence of asthma was similar in all of the schools surveyed (approximately 5.5%), but the prevalence of rhinitis and atopic dermatitis was higher in the urban schools (24.3% and 12.5%, respectively) than in suburban schools (15.7% and 7.2%, respectively). The results of logistic regression analysis showed that the potential environmental factors that are significantly correlated with allergic disorders among children include diesel engine vehicles; the use of antibiotics and paracetamol; ingestion of nuts; contact with dogs and cats in the first year of life; contact with farm animals by mothers while pregnant; and maternal cigarette smoking. Lung function measurements in asthmatic and non-asthmatic school children were also conducted at rest and following exercise, but no cases of exercise-induced asthma were identified.

It was found that the standardized ISAAC questionnaire was useful in assessing the prevalence of asthma and allergic diseases in epidemiological investigations such as the Chiang Mai study. However, there were some limitations related to the questionnaire being originally developed for application in Western countries and some questions, particularly those on food variables (e.g. bread, pasta, butter, fast food), were not suited to the dietary culture of Chiang Mai children. In addition, Thai wording to explain a wheezing symptom used in the questionnaire was a sound of '/wi:d/', which may not be as understandable as '/ha:də/' (a sound of deep breath) (Phankingthongkum *et al.*, 2002). The misunderstanding concerning the wheezing and other symptoms was resolved by telephone interview with some parents. Furthermore, it was felt that parent's memories may not always be reliable when asking about the past symptoms of their children such as the month when symptoms occurred (subject to recall bias).

Although the results suggest that the prevalence of rhinitis and atopic dermatitis was higher in the urban than in suburban schools, it cannot be unequivocally concluded that this was mainly due to air pollution. Better understanding of the correlation between exposure to air pollutants and allergic prevalence would be obtained if air quality data (daily or monthly average) for at least the preceding 12 months were available for each school area.

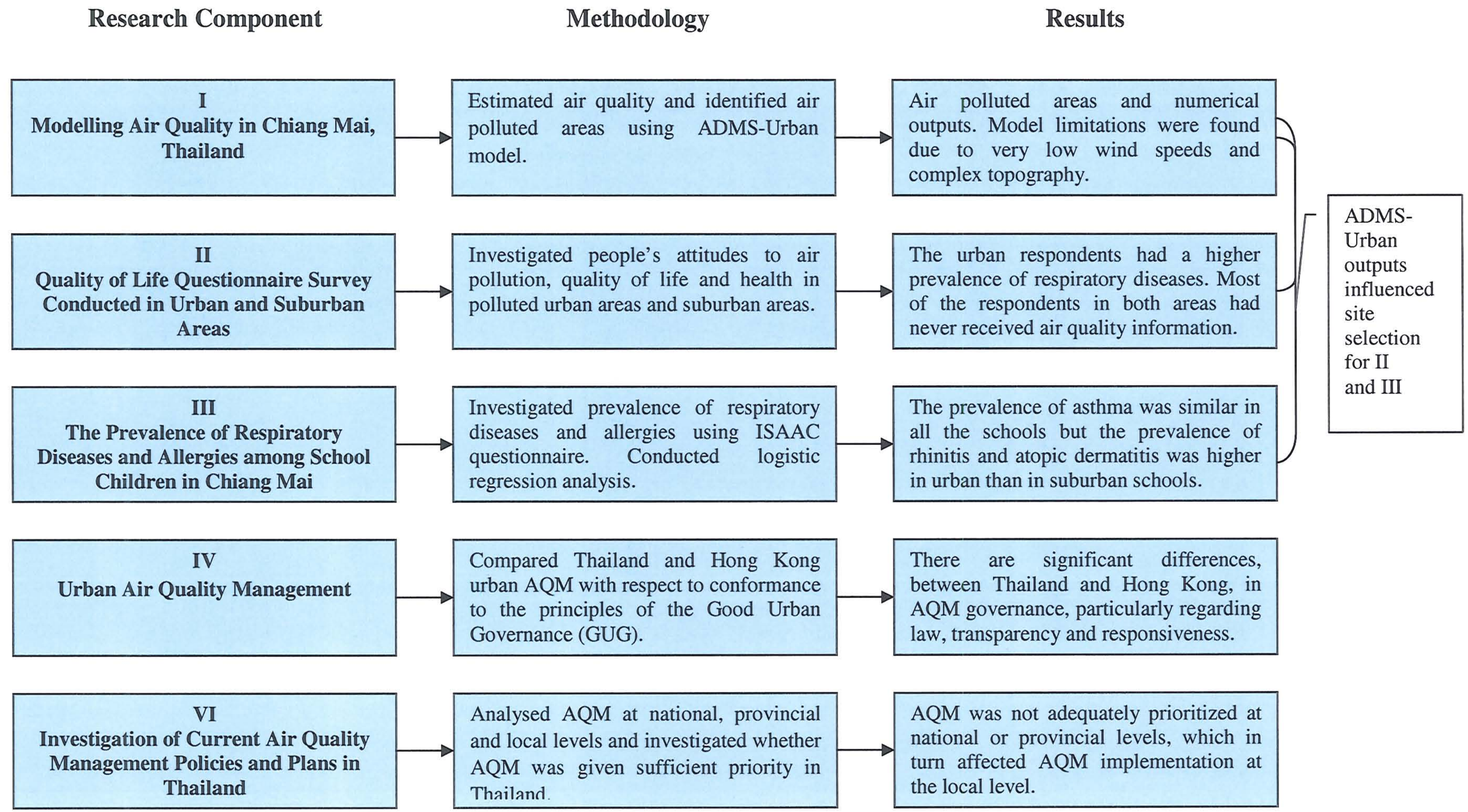


Figure 7.1 Chart illustrating major research components, methodology and results of the PhD research study titled 'Local Air Quality Management and Health Impacts in Thailand'

7.1.4 Urban Air Quality Management

By application of the GUG principles, a comparison of AQM in Thailand with that of Hong Kong SAR clearly showed the differences in urban governance, particularly with respect to law, transparency, responsiveness and accountability. Eight GUG characteristics were analysed by taking account of available information from different sources (e.g. literature references and personal communication). In addition, AQM aspects undertaken in Hong Kong were investigated during the author's visit to the HK Environmental Protection Department (EPD). It was observed that EPD not only has an advanced and effective AQM system but that its operation is also consistent with good governance. Some GUG characteristics in Chiang Mai were explained in relation to specific examples and therefore it is acknowledged that they may not be truly representative of the wider situation. However, it is considered that these examples provide a reasonable indication of urban governance with respect to current AQM practice in Thailand.

With respect to GUG, the AQM situation in Thailand is: i) low participation of women at an executive level in local government organizations; ii) outdated environmental laws and regulations, and partial law enforcement; iii) lack of effective air quality information in Chiang Mai; iv) lack of effective mechanisms to respond to public complaints; v) inability to maintain local stakeholder meetings established in the previous AQM projects (i.e. MAQHUE and MDE projects); vi) lack of public consultation regarding EIA reports; vii) lack of transparency in decision making processes with could lead to corruption. It was concluded that these urban governance problems need to be properly addressed by government organizations at all levels (i.e. national, provincial and local) in order to produce an LAQM system that is consistent with GUG.

7.1.5 Investigation of Current Air Quality Management Policies and Plans in Thailand

At a national level, AQM prioritisation was investigated by analysing current policies and plans concerning air pollution abatement (e.g. the 9th NESDP, Government's plan, national pollution mitigation policy and environmental education). To understand the provincial situation, the development strategy of Chiang Mai was reviewed, including fund allocations to development projects where it related to AQM. For the local level, a questionnaire survey was conducted with local government officials in the Sub-district Administration Organisations (SAO) and Sub-district Municipalities (SM) in order to assess the current level of environmental awareness, particularly those relating to air pollution (see Section 6.2).

It was found that AQM was not given a high priority in recent national plans. Due to the non-specific nature of the guidelines and frameworks in these plans, it was difficult for government organizations at the provincial and local levels to establish AQM action plans for implementation. This omission of AQM prioritization at the national level has resulted in the failure of effective decentralization of AQM to both provincial and local levels in terms of the allocation of budgets and expertise. The results of the local level questionnaire survey indicated that SAOs and SMs in Chiang Mai did not include LAQM in their strategic work plans mainly due to an inadequacy of technical knowledge (lack of environmental personnel) and lack of both financial and technical assistance.

7.2 Recommendations for Sustainable Measures to Improve Air Quality in Chiang Mai

Local air quality management (LAQM) requires the involvement of a broad range of stakeholders; not only the government agencies responsible for environmental and urban management (listed in Section 1.5.1), but also other agencies responsible for law enforcement, health promotion, best agricultural practice (BAP) promotion and public relations. The following measures are recommended for LAQM based mainly upon the results and evidence obtained from the research components under this PhD programme, however, evidence from other studies (e.g. JICA study) was also taken into consideration. As part of these recommendations, each measure is directed to the relevant agencies based upon their responsibilities (e.g. concerning pollution control, environmental and urban management, law enforcement, etc.). Where possible, recommendations are aimed at the major government agencies located in Chiang Mai given the scope of their responsibilities and consistent with the decentralization of authority. Where there is any inadequacy in LAQM capacities, central government agencies (such as PCD), are recommended to provide support (e.g. technology transfer, financial assistance and technical advice).

7.2.1 Development of an Emissions Inventory for Chiang Mai Province

The project, aiming to build the capacity of air quality departments at federal (PCD) and provincial (CMM) levels was conducted in 2001-2002 in co-operation with the US-AEP and MDE (CMM, 2002b). As part of this project, a 2001 emissions inventory for CMM was constructed (see Section 2.2.1). Since then and as of June 2005, the emissions inventory for CMM had not been updated and there was no provincial plan to develop a complete emissions inventory for Chiang Mai province. Nevertheless, CMM has declared its intention to ask Chiang Mai University to update the emissions inventory. However, no schedule and budget have been approved (pers. comm. Ms. Rongrong Duriyapan) and even if this went ahead, an emissions inventory for only the area for which CMM is responsible is insufficient to obtain the necessary information to tackle air pollution problems throughout the province.

The Air Pollution in the Megacities of Asia (APMA) project and the Clean Air Initiative for Asian Cities (CAI-Asia) (2004) indicated that one of the major obstacles to AQM development in Asian countries is the lack of comprehensive emissions inventories and quality-assured emission data. As a result, air quality modelling cannot be effectively conducted due to a lack of reliable input data (see Section 7.1.1). Moreover, the results reported in Chapter 6 illustrate that the importance of an emissions inventory developed for Chiang Mai province is not yet appreciated at a provincial level (not yet included in the provincial plan). This is so, even though such an inventory would help policy makers and researchers assess anthropogenic effects on atmospheric pollution and plan minimisation strategies. For example, it would assist stakeholders, including the public, to understand the major air pollution sources and contribute towards effort to reduce pollutant emissions in the province. In addition, an emissions inventory would help identify seriously air polluted areas in Chiang Mai and would, therefore, be a useful tool for land use planning (e.g., relocation of air polluting factories and granting of permits for housing estates, factories, etc.). If such an emissions inventory was kept regularly updated (e.g. annually or bi-annually), policy makers could keep track of the effectiveness of existing air quality management measures taken within the districts and sub-districts of Chiang Mai Province. As noted above, a complete and up-to-date emission data set is important for air dispersion modelling studies to accurately identify and predict air pollution 'hot-spots' assuming different action and development scenarios (see Chapter 2). It is therefore recommended that such an inventory be produced and maintained as a matter of urgency.

Table 7.1 Recommended agencies and actions for the development of an emissions inventory for Chiang Mai Province

Recommended agencies	Actions
Pollution Control Department (PCD), Bangkok	Act as programme leader. Provide technical support. Request funding from Ministry of Natural Resources and Environment (MONRE) or international aid organizations.
Department of Environmental Engineering, Chiang Mai University	Construct an emissions inventory for Chiang Mai.
Chiang Mai Office of Public Works and Town and Country Planning (CMOPT)	Provide GIS/mapping support regarding location of point, road and area sources in Chiang Mai.
Chiang Mai Provincial Industry Office (PIO)	Provide information regarding locations, contact details, type and size of industry, and raw materials used.

7.2.2 Improvement of Air Quality Monitoring Data

As mentioned in Section 1.5.2.2, the general ambient monitoring station located at Chiang Mai's Provincial Hall is not appropriate with respect to siting criteria due to its being located next to a car park and local road, and surrounded by mature vegetation. The roadside monitoring station is also located adjacent to a 20m high tree (within a distance of 5m). These may have an impact on monitoring data (Section 2.7). It is the responsibility of PCD to resolve such siting problems. Immediate actions which should be taken are the trimming the branches or removal of some trees that obstruct wind flow. Consideration should also be given to moving the monitoring stations to appropriate sites.

Furthermore, the non-existence of baseline data for Chiang Mai makes it impossible for AQM decision makers to see clearly how air quality in Chiang Mai is changing. The lack of current background air quality data for Chiang Mai can also substantially restrict the application of air modelling research (see Sections 2.2.3 and 2.7). PCD could overcome this problem by monitoring background concentrations using one of their mobile monitoring stations. Based on seasonal wind direction, it is recommended that background concentrations be monitored in the north or northwest of Chiang Mai in areas such as Mae Rim District (outskirts of Muang District) in the dry season, and southeast of Chiang Mai (e.g. Ban Thi District, Lamphun Province) in the wet season (Section 2.2.3). In addition, air quality at probable air pollution 'hot-spots', such as at main traffic junctions and roads or near polluting industries, should be conducted on a regular basis. This would provide useful information for decision makers to evaluate the effectiveness of AQM and urban planning measures applied in Chiang Mai.

Table 7.2 Recommended agencies and actions for improving air quality monitoring data

Recommended agencies	Actions
i) Pollution Control Department (PCD), Bangkok	Act as programme leader. Improve surroundings of existing air monitoring stations. Monitor background concentrations and air quality at probable 'hot-spot' areas.
ii) Chiang Mai University (CMU) (Departments of Chemistry and Environmental Engineering)	Where PCD do not have sufficient technicians to work in Chiang Mai on a regular basis, PCD could contract CMU to conduct monitoring programmes PCD may have to provide equipment for sampling and analysis.

7.2.3 Dissemination of Air Quality Information

The findings from the Quality of Life questionnaire survey (Chapter 3) suggested that many residents in Chiang Mai have never received air quality information, which indicates a lack of effective dissemination of such information. In addition, it was found that the information of principal interest included: current and past air quality; air quality forecasts; source type and impacts of air pollution; and how to avoid and mitigate air pollution (Table 3.21). Furthermore, television was the medium most preferred for receiving such information (Table 3.22). In order to improve the situation, PCD should provide this information to the Public Relations Department Region 3 (PRD3). PRD3 is responsible for public relations activities (e.g. news, information, entertainments, information exchange) *via* 10 radio stations (FM and AM) and a television channel (Channel 11) in 8 Northern provinces (including Chiang Mai). Information concerning current air quality (air quality index and air quality forecast) can be announced with daily news programmes on both television and radio. PRD3 also maintains a website http://www.prdnorth.in.th for the dissemination of news and general information to the public, which could be useful for posting additional air quality information provided by PCD.

Table 7.3 Recommended agencies and actions for the dissemination of air quality information

Recommended agencies	Actions
i) Public Relations Department Region 3 (PRD3)	Disseminate daily air quality information and forecast with news programmes via television, radio and internet.
ii) Pollution Control Department (PCD), Bangkok	Provide up-to-date air quality information to PRD3.

7.2.4 Abatement of Pollution from Traffic Sources

7.2.4.1 Public transport system

One of the major causes of air pollution in Chiang Mai is road traffic (e.g., congestion, high number of motor vehicles during rush hours). The results of air modelling (Chapter 2) showed that probable air pollution 'hot-spots' were located outside Muang district (within the Saraphi and Hangdong districts). Therefore, designing a public transport system only for Muang district, as currently planned, is unlikely to effectively solve traffic-related air pollution problems in the province. The public transport network, particularly buses, should be planned to meet the needs of all people living in the different urban areas and who normally travel to work or study in Muang district. Therefore, at the very least, the network for public transport should link 7 major urban districts – Muang, Mae Rim, Doi Saket, San Sai, San Kampang, Saraphi and Hangdong (Figure 7.2). Moreover, an economic feasibility study should be conducted for the establishment of a public transport system for Chiang Mai in the future (e.g. investment cost, pay-back period, business and strategic planning, management, logistics) in order to avoid the problems experienced in the CMM's Chiang Mai Bus (CMB) project. CMB is not currently profitable and is a cause for concern if it is not self-sufficient in the long term (pers comm. Mr. Panyapol Mongkolchareon).

Table 7.4 Recommended agencies and actions for the establishment of a public transport system in Chiang Mai

Recommended agencies	Actions
i) Chiang Mai Office of Public Works and Town and Country Planning (CMOPT)	Act as a programme leader for public transport route planning.
ii) Chiang Mai Provincial Land Transport Office (PLTO)	Approve proposed routes of public transport.
iii) Chiang Mai Public Transportation, Chiang Mai Municipality (CMM)	Share experience in establishing the Chiang Mai Bus operation. Possibly operate LPG buses.
iv) Department of Engineering, Chiang Mai University (CMU)	Provide technical advice and conduct a feasibility study
v) Provincial Office of Natural Resources and Environment (PONRE) & Environmental Region 1	Promote the use of public transport

7.2.4.2 School bus system

From an interview survey conducted as part of the JICA Study, the highest proportion of 'songtaew' passengers (31.44%) were students. Decision makers should plan routes for school buses using a GIS database available at the Chiang Mai Office of Civil Works and Town and Country Planning (OCTCP). For example, one of the shape files developed for an ArcView™ application shows the locations of all schools, universities and colleges within the urban plan area (Figure 7.2). Using this information, optimum routes can be determined for school buses. Three routes are suggested: Highway 106 (Hangdong district); Highway 108 (Saraphi district), Muang district. The 42 schools and academic institutes that would benefit from such routes are listed in Table 7.5. It is suggested that air-conditioned LPG minibuses similar to those operated by CMB should be used as school buses. In contrast, old 'songtaews' that produce black smoke should not be used for such a programme because of the risks to passenger health, especially asthmatics and those with respiratory allergies aggravated by exposure to polluted air.

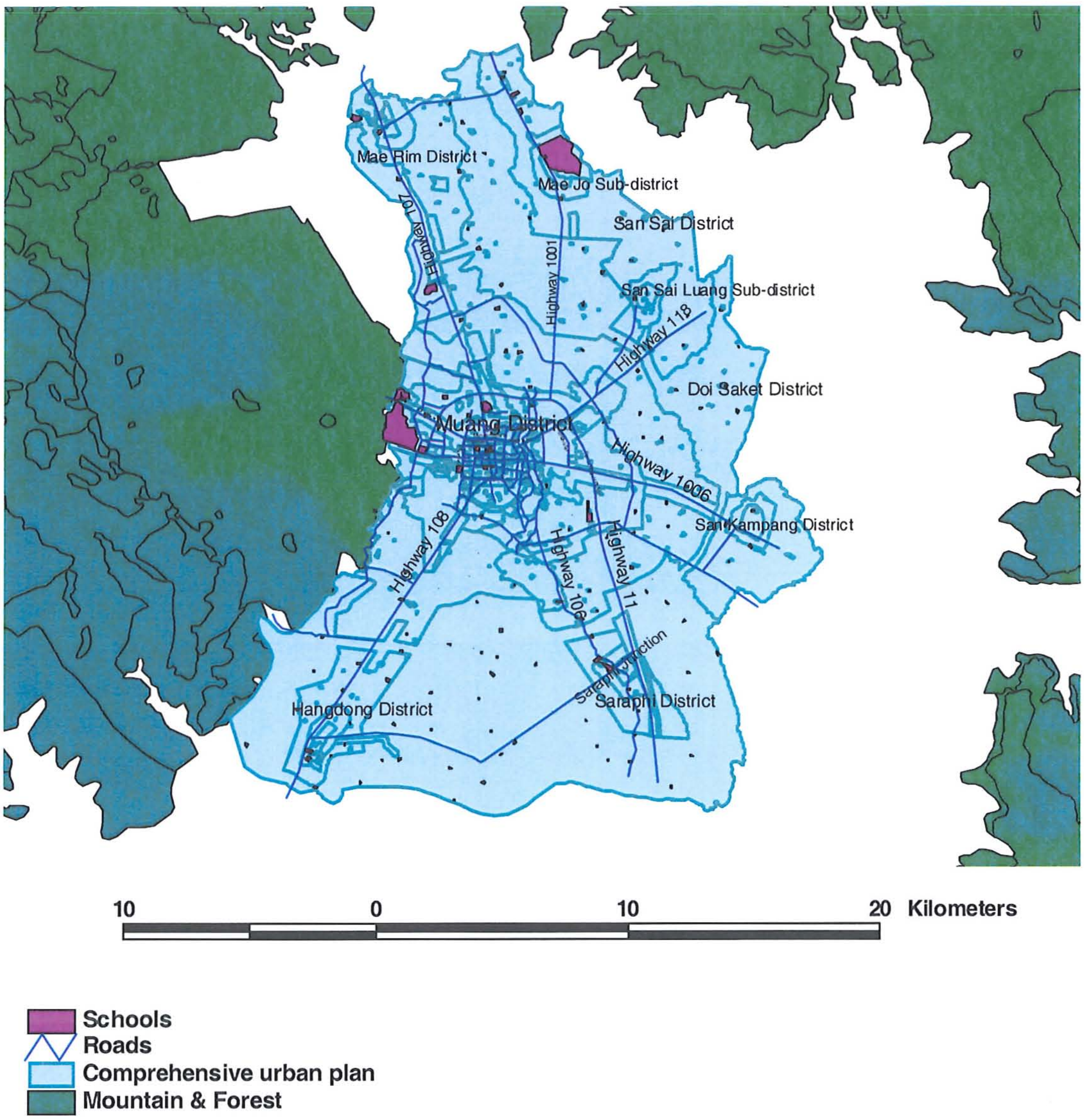


Figure 7.2 An ArcView™ GIS map illustrating the location of schools and other academic institutes, as detailed in the Comprehensive Urban Plan area of Chiang Mai

Table 7.5 List of academic institutes in 3 districts that may benefit from a school bus service.

Zone	School/University/College
A. Muang district	Wat Chang Kien School; Sarapat Chang College; Chiang Mai University; Wattano Payup School; Chiang Mai Technical College; Chiang Mai Vocational College; Yuparaj Wittayalai School; Puttisopon School; Chiang Mai Kindergarten; Tedsaban Sri Pingmuang School; Tedsaban Thasatoi; Tedsaban Wat Papang; Chiang Mai Sports College; Chiang Mai Rajapat Institute; Wat Patun School; Wat Kajao School ***(10 schools; 5 colleges; 1 university)***
B. Hangdong district	Sirimagklajarn Schools; Ban Donpin; Ban Patal; Wat Thavorndham School; Ban Sanpakwan School; Ban San Pasak; Tao Bunruang School; Ban Rai School; Ban Dong School; Wat Changkham School; Wat Saimoon (Nart Kasem Songkroh); Hangdong Ratharaj Ouppatham School; Wat Sri Supan School; Ban Nam Phrae School ***(14 schools)***
C. Saraphi district	Wat Pranon Nongpueng School; Wat Kongsai School; Wat Pakaayong School; Wat Weruwa School; Saraphi Pittayakom School; Waranekoon Kindergarten; Wat Sripotaram School; Sunday Buddhism School; Wat Bupparam School; Wat Bankong Community School; Wat Nongsijang School; Wieng Setthi Wittaya School ***(12 schools)***

Table 7.6 Recommended agencies and actions for establishing a school bus service in Chiang Mai

Recommended agencies	Actions
i) Chiang Mai Office of Public Works and Town and Country Planning (CMOPT)	Initiate the programme and act as a programme leader. Plan bus routes using Chiang Mai's Comprehensive Urban Plan and GIS data.
ii) Provincial Office of Natural Resources and Environment (PONRE)	Conduct environmental awareness raising scheme.
iii) Chiang Mai Provincial Education Office (PEO)	Liaise with schools and other educational institutes in Chiang Mai. Include this school bus programme in the provincial education action plan.
iv) Chiang Mai Public Health Office (PHO)	Promote health awareness and benefits from the use of school buses.
v) Chiang Mai Municipality (CMM)	Operate LPG bus service.

7.2.4.3 Control of polluting vehicles

Under the project *Air Quality Management in Chiang Mai and Lamphun Provinces*, one of the main activities recommended to tackle air pollution from traffic is the establishment of an inspection team to enforce black smoke regulations as in the PCD's Developing Integrated Emission Strategy for Existing Land Transport (DIESEL) Programme, undertaken in Bangkok Metropolitan (see Section 6.3.4). Currently, this inspection task and on-road enforcement is the responsibility of the Traffic Police, but it is recommended that the Chiang Mai Office of Public Health should become involved in order to raise consciousness, among car owners, of the health effects in addition to the enforcement component. Another suggestion is that in order to encourage public participation, concerned members of the public should be included in the inspection programme on a volunteer basis – in a similar way to the Smoky Vehicle Control Programme of the HK EPD (see Section 5.5.4.1) and PCD's DIESEL programme. PCD can support this activity by training staff of the Provincial Office of Natural Resources and Environment (PONRE) to plan and implement such a programme, including the application of emission analyzer systems as used in PCD's Automotive Emission Laboratory (PCD, 2004c).

Table 7.7 Recommended agencies and actions for improved control of polluting vehicles

Recommended agencies	Actions
i) Pollution Control Department (PCD), Bangkok	Initiate the programme and act as programme leader. Conduct automotive emission tests with PONRE and a local inspection team. Promote a motor maintenance programme to reduce black smoke. Provide technical advice and support (e.g. training PONRE staff).
ii) Provincial Office of Natural Resources and Environment (PONRE)	Act as logistical coordinator. Establish an inspection team.
iii) Chiang Mai Provincial Police	Conduct on-road enforcement with PCD and PONRE official. Work with local inspectors (e.g. trained volunteers, university students)

7.2.4.4 Campaign for the use of bicycles

i) Promotion of road safety

The use of bicycles is appropriate for Chiang Mai, especially in the City Municipality area (approximately 60 km^2), but road safety concerns restrict their promotion. The problem observed in bike lanes in Bangkok was that motorcycles used them as well, which makes them unsafe for the cyclists. The JICA Study noted that the level of safety awareness was relatively low among drivers, motorcyclists, and pedestrians in Chiang Mai (JICA, 2002). For example, drivers and motorcyclists failed to stop at intersections when the traffic lights turned red; three or more persons rode on one motorcycle at the same time; pedestrians cross the street without regard for the location of crosswalks.

It is important that plans to construct bike lanes and promote the use of bicycles should be accompanied by serious efforts to promote road safety for all. Drink driving has come to be viewed as a serious offence in Thailand and is the subject of a government publicity campaign. The drink driving regulations have not actually been enforced for all roads in Chiang Mai, and furthermore, the enforcement operation by traffic police is in 2 shifts – morning (from 6 a.m. to 9 a.m.) and afternoon (from 3 p.m. to 6 p.m.) and misses many times when drivers could be driving under the influence of alcohol. The fact is that many road users lack discipline and overall, road safety needs to be both encouraged and enforced before a campaign encouraging the use of bicycles could be responsibly and safely implemented.

ii) Organising events to promote the use of bicycles

The use of bicycles can be promoted by organising events with various themes (e.g., Bike for Clean Air; Bike for Better Health; Bike for Children with HIV) and holding cycling tournaments. To highlight health aspects, Chiang Mai Office of Public Health could also contribute by providing health checks (e.g., weight, respiratory health) during such promotional events. Bicycle use can also be promoted together with cultural conservation. For example, the water-colour painting (Figure 7.3) illustrates cyclists on Highway 106 (Saraphi district to Lamphun Province), one of the conservation sites in Chiang Mai (permission to use this painting granted by the artist). For a more sustainable and continuing approach, government organisations in Chiang Mai could designate a Clean Air Week as an annual event starting each year around the beginning of the dry season (end of November – December). This would raise awareness of the causes and avoidance of air pollution, for example from burning of dry vegetation, wastes and, more seriously, forests. In Chiang Mai, the highest PM_{10} concentrations were often recorded in the dry season. Moreover, a Car Free City Day could be considered for Chiang Mai, for example, within the area bounded by the moat in Muang (City) District, or along part of Highway 106 in Saraphi District. This would work in the same way as the Sunday Walkway Scheme in Tha Pae area within the moat, which was started to promote Chiang Mai handicraft products to shoppers. However, it should be noted that the roads are very crowded with stalls and shoppers strolling on the roads and not always suitable for cyclists.

iii) Designated bike lanes

Bike lanes should be shaded by trees in Chiang Mai because the sun is very strong – especially in the dry season. Tree planting along the roads should be planned together with bike lane construction. Places for bike parks should be well equipped with parking facilities. Plans to prevent motor vehicle drivers parking or driving across/in the bike lanes should also be considered.

Illustrated by Thanakorn Chaijinda

Figure 7.3 Cycling on Highway 106 (Saraphi District to Lamphun Province)

Table 7.8 Recommended agencies and actions for the promotion of bicycle campaign

Recommended agencies	Actions
i) Chiang Mai Municipality (CMM)	Act as programme leader as well as provide an official agreement for bike lane construction in Muang District. Provide financial support in construction.
ii) Chiang Mai Office of Public Works and Town and Country Planning (CMOPT)	Design bike routes as well as construct bike lanes.
iii) Provincial Office of Natural Resources and Environment (PONRE)	Promote the use of bike lanes as part of the environmental quality management action plans. Undertake public participation role by liaising with local government organizations, NGOs and academia, encouraging them to support the bicycle-use promotion programme.
iv) Chiang Mai Environment Office Region 1 (EO1)	Act as a funding channel from MONRE for public awareness raising programmes in road safety as well as organising and promoting bicycle events for the public.
v) Chiang Mai Public Health Office (PHO)	Promote awareness of health and other benefits from the use of bicycles. Provide health checks during organised events.
vi) Chiang Mai Provincial Police	Promote road-safety campaign. Conduct on-road enforcement.

7.2.5 Control of Open Burning

7.2.5.1 Rice stalk burning control

The removal of rice stalks in the vast areas that have been used for rice and maize growing is a difficult problem for Thai farmers. The easiest and fastest way to solve this problem is to burn fields in order to prepare the land for the next growing season. This is because farmers cannot afford expensive ploughing equipment to bury stalks without burning. In Chiang Mai, the major rice growing districts are San Sai, Doi Saket, Chiang Dao, Hod and Phrao. In 2002 – 2003, the estimated rice growing areas, during the dry season and wet season, were approximately 60 million m^2 (37,450 rai) and 890 million m^2 (556,285 rai), respectively (source: Chiang Mai Office of Statistics). The Chiang Mai Provincial Agricultural Extension Office (PAEO) should co-operate with the Public Warehouse Organization (PWO) to help farmers who grow rice and maize by investing in ploughs and operating a ploughing service. Major PAEO responsibilities are to help farmers increase agricultural production efficiency and improve the quality of the products, as well as to provide technology and knowledge (Nualvatna, 2003). In contrast, the main PWO internal trade activities are to purchase agricultural products (e.g. rice, maize, green bean, soy bean) and sell the products under the price stabilisation policy of the government. The ploughing service could be exchanged for an appropriate percentage of agricultural products produced. This would benefit the farmers and the government and, at the same time, reduce emissions from agricultural burning.

To resolve agricultural waste burning problems, PCD and the Department of Agricultural Extension (DOAE) undertook a demonstration programme in 2003 to promote best agricultural practices (BAP), mainly to rice farmers. The activities included an introduction to ploughing practice and utilization of agricultural wastes (e.g. fertiliser production). Under this demonstration programme, approximately 480 farmers in four provinces, including Chiang Mai, were provided with practical BAP knowledge, and 300 farmers established a network.

Table 7.9 Recommended agencies and actions for control of rice stalk burning

Recommended agencies	Actions
i) Chiang Mai Provincial Agricultural Extension Office (PAEO)	Act as programme leader. Apply similar tasks as the 2003 PCD and DOAE project. Educate local farmers (e.g. ploughing technique and fertiliser production using agricultural wastes). Encourage farmers to join the existing BAP network. Establish a ploughing service in support of farmers
ii) Provincial Office of Natural Resources and Environment (PONRE)	Assist PAEO by raising the environmental awareness of farmers and SM/SAO officials (e.g. publish guidance notes, organise exhibitions). Follow up the results of the programme with BAP network members.
iii) Pollution Control Department (PCD) and Department of Agricultural Extension (DOAE), Bangkok	Act as consultants to PAEO and PONRE.
iv) Public Warehouse Organization (PWO), Bangkok	Provide funding to PAEO to purchase ploughing machines.

Note: DOAE, under the Ministry of Agriculture and Cooperatives (MOAC), is responsible for providing farmers with advice and technologies consistent with appropriate agricultural practices. PAEO is a provincial office of DOAE (DOAE, 2005).

7.2.5.2 Other agricultural wastes

Alternative control approaches should also be investigated for other agricultural products such as 'longan', an important economic fruit of Chiang Mai. 'Longan fruit' farmers normally prune the branches and leaves after harvesting - around August to September. Jomtong, Saraphi, San Patong and Doi Lor are major longan growing districts. Smaller growing areas exist in many other areas in Chiang Mai. In 2002, the total longan growing area in Chiang Mai Province was approximately 364 km^2 (227,482 rai). It is recommended that the Learning Centre of the King Bhumibhol's Philosophy of Economic Sufficiency establishes a Fertiliser Bank using longan and other agricultural wastes. These are suitable raw materials for organic fertiliser production. The Learning Centre was established in 2001 and located in Mae Rim District. It promotes examples of best agricultural practices. This project could be financed by the Ministry of Science and Technology (MOST). Local farmer groups should co-operate with the Learning Centre through their local administration organizations, who would act as coordinators for the organic fertiliser network. Incentives for farmers to bring the waste to the Fertiliser Bank could include the provision of organic fertilisers. However, a feasibility study should initially be conducted.

Furthermore, Chiang Mai has the capability to continue the BAP programme (see Section 7.2.5.1) and expand the practices promoted to cover other agricultural wastes. Chiang Mai University (Faculty of Engineering) and Maejo University (Maejo Institute of Agricultural

Technology) can contribute to this programme through their research and development (R&D) projects in the utilization of local agricultural wastes.

Table 7.10 Recommended agencies and actions for controlling of other agricultural wastes

Recommended agencies	Actions
i) Learning Centre of King Bhumibhol's Philosophy of Economic Sufficiency	Establish the Fertiliser Bank programme. Act as a focal point. Operate the pilot fertiliser production process and educate and train farmers in production techniques.
ii) Ministry of Science and Technology	Provide funding for the Learning Centre to establish a fertiser production system.
iii) Chiang Mai University and Maejo University	Act as technical advisers. Conduct research regarding alternative utilization of different agricultural wastes (e.g. biofuel production).
iv) Chiang Mai Provincial Agricultural Extension Office (PAEO)	Promote the programme with farmers in Chiang Mai. Encourage them to establish Fertiliser Banks in each sub-district. Act as a funding channel (with MOAC) to subsidise fertiliser production facilities with SMs and SAOs.
v) Provincial Office of Natural Resources and Environment (PONRE)	Conduct an awareness raising programme aimed at farmers (e.g. publish guidance notes, organise exhibitions)

Note: MOAC = Ministry of Agriculture and Cooperatives

7.2.6 Control of Air Pollution from Industrial Sources

The control of dust from construction sites, including construction material transportation, should follow PCD's Code of Practice for Dust Control for Construction Activities (also mentioned in Section 5.6 (iii)). There are major dust sources within the industrial sector in Chiang Mai. Taking as an example, concrete batching plants (Figure 7.4), on a visit to a site typical of many in Chiang Mai, the author observed no apparent measures to control the release of dust from the operation. Responsible agencies (DIW, PCD) should consider taking action to control air polluting production processes (see Sections 1.5.1.3i and 1.5.1.2). This could take the form of the recommendation of dust control measures, the promotion of ISO14001 certification and the enforcement of existing regulations [Factory Act (1992), Enhancement and Conservation of National Environmental Quality Act (1992)]. Dust creating industries should not be allowed to be located either within residential areas or near educational institutes and temples. It is the direct responsibility of the Department of Industrial Works (DIW) to regulate polluting industrial activities, under the Factory Act (1992). DIW should provide a guidance note for the industry such as the

HK EPD's_Guidance Note for the Best Practicable Means for Cement Works (Concrete Batching Plant) (EPD, 1993) (Box 7.1).

Photographed by Mr. Apisak Kumthong
(Note: Permission was received from Mr. Kumthong to use this photograph)

Figure 7.4 A concrete batching plant operated by Nakornluang Concrete Co. Ltd., Muang District

Box 7.1 Summary of control measures for concrete batching activities from HK EPD's *Guidance Note for the Best Practicable Means for Cement Works* (EPD, 1993)

Guidance Note for the Best Practicable Means for Cement Works (Concrete Batching Plant)
Environmental Protection Department (EPD), Hong Kong SAR
Control measures for concrete batching activities

Emission limits: Particulate 50 mg/m^3

Boundary ambient standards: TSP 260 $\mu g/m^3$ (24-hour average); PM_{10} 180 $\mu g/m^3$ (24-hour average)

Cement and other dusty materials: The loading, unloading, handling, transfer or storage of cement, pulverized fuel ash and/or other equally dusty materials shall be carried out in a totally enclosed system. All dust-laden air or waste gas generated by the process operations should be properly extracted and vented to fabric filtering system to meet the emission limits.

Other raw materials: The raw materials (such as crushed rock, sand and stone aggregate) shall be adequately wetted prior to and during the loading, unloading and handling operations. Manual or automatic water spraying systems shall be provided at all unloading areas, stockpiles and material discharge points. Belt conveyors for handling raw materials shall be enclosed on top and 2 sides with a metal board at the bottom to eliminate dust emission due to wind-whipping effects.

Loading of material for batching: Pre-mixing of material in a totally enclosed concrete mixer before loading into the concrete truck is recommended. All dust-laden air generated by the pre-mixing process as well as the loading process shall be vented to a fabric filtering system. The loading bay shall be totally enclosed during the loading process.

Vehicles: All practicable measures shall be taken to prevent or minimize dust emission caused by vehicle movement. All access and route roads within the premises shall be paved and adequately wetted. Vehicle cleaning facilities shall be provided and used by all concrete trucks after loading and other vehicles leaving the premises to wash off any dust and/or mud deposited on the wheels and/or vehicle body.

Housekeeping: A high standard of house keeping shall be maintained. All spillages or deposits of materials on ground, support structures or roofs shall be cleaned up promptly. Any dumping of materials at open areas shall be prohibited.

Table 7.11 Recommended agencies and actions for controlling dust from industrial sources

Recommended agencies	Actions
i) Department of Industrial Works (DIW)	Act as programme leader. Produce guidance notes specifically for each polluting industry (particularly major PM_{10} emitters). Monitor production processes and regulate factories as specified in the Factory Act (1992)
ii) Thailand Environment Institute (TEI)	Work with DIW in promotion of the Environmental Management System (ISO14000 series). Monitor environmental management (EM) performance under ISO14000 programme.
iii) Provincial Office of Natural Resources and Environment (PONRE)	Evaluate performance of environmental management by conducting routine PM_{10} monitoring at factories operating dust-creating processes.
iv) Pollution Control Department (PCD)	Enforce the pollution control regulations as specified by the Enhancement and Conservation of National Environmental Quality Act (1992)
v) Chiang Mai Provincial Industry Office (PIO)	Provide logistical coordination with DIW and TEI. Liaise with factories. Assist DIW and TEI in EM monitoring.

Note: TEI (a Thai NGO) provides Environmental Management System (EMS) services to industries and issues certificates under the ISO14000 series (TEI, 2005).

7.2.7 Cleaner Production Application

In 2004 – 2005, the major proportion of funds for development projects relating to industry was allocated for improving products, marketing, trading, human resource development, etc. (see Tables 6.2-6.3). In the project *Air Quality Management in Chiang Mai and Lamphun Provinces*, a small percentage was allocated to the control air pollution from point sources in the CMM area. To reduce air pollution contributed by industry, Cleaner Production (CP) should be applied in order to reduce pollution from every production process at its source. CP is defined by the United Nations Environment Programme (UNEP) as in Box 7.2. Other conceptual frameworks related to CP are Pollution Prevention (typically used in North America) and Waste Minimisation which has been adopted by the US EPA. All embrace a similar objective that is to reduce pollution and avoid waste creation at the source. CP represents a preventative approach to environmental management. It refers to how goods and services may be produced with the minimum environmental impact under present technological and economic limits (UNEP, 2001).

Box 7.2 Definition of Cleaner Production

Definition of Cleaner Production by UNEP

Cleaner Production (CP) is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society.

For production processes, CP results from one or a combination of conservation of raw materials, water and energy; elimination of toxic and dangerous raw materials; and reduction of the quantity and toxicity of all emissions and wastes at source during the production process.

For products, CP aims to reduce the environmental, health and safety impacts of products over their entire life cycles, from raw materials extraction, through manufacturing and use, to the ultimate disposal of the product.

For services, CP implies incorporating environmental concerns into designing and delivering services.

Source: UNEP (2001)

In Thailand, the Pollution Control Department has established the Thailand Network of Eco-efficiency and Cleaner Production (TNEC) in order to promote the application of cleaner technology (CT). The Thailand Environment Institute (TEI), a member of the Asia Pacific Roundtable for Cleaner Production (APRCP), has introduced CT research and development, promotion and training programmes in Thailand (e.g. in the pulp and paper industry, food industry, hotels). In Chiang Mai, responsible government organisations should not only be applying and enforcing regulations, but also actively promoting CP capacity building for the industrial sector. The Department of Environmental Engineering, Chiang Mai University has expertise in this subject and could provide technical support to PONRE, EO1 and PIO in planning a CT promotion programme and conducting government staff training.

Table 7.12 Recommended agencies and actions for application of Cleaner Production

Recommended agencies	Actions
Pollution Control Department (PCD), Bangkok	Act as programme leader. Provide funding to TEI and CMU.
Thailand Environment Institute (TEI), Bangkok	Work with CMU to strengthen local CT capacity through government staff training (e.g. PONRE, EO1, PIO) as well as promotion of CT technology to a range of industries in Chiang Mai.
Faculty of Engineering, Chiang Mai University	Provide logistical and technical support.
Chiang Mai Provincial Industry Office (PIO)	Provide information regarding locations, contact information, type and size of industry and raw materials used.

7.2.8 Environmental Education and Awareness

It is crucial to promote, not only formal, but also informal environmental education (EE) and awareness in Chiang Mai. For students, the Chiang Mai Office of Regional Education should promote EE at schools. Topics covered should include waste separation, the production of organic fertilisers from wastes, recycling, etc. To create environmental awareness among children, activities such as camping, and walking in the forest should be promoted. The Learning Centre of King Bhumibhol's Philosophy of Economic Sufficiency offers informal EE in the form of camping programmes for students where they can also learn about best agricultural practices that are 'friendly' to the environment (e.g. organic farming). Another example is the Queen Sirikit Botanic Garden (QBG) in the Mae Rim district, which was the first botanical garden in Thailand. QBG serves as a centre for botanical studies and research, a centre for *ex situ* conservation of the Thai flora, and also provides botanical education and aesthetic displays for members of the public and tourists. Furthermore, one of Queen Sirikit's initiatives is the Programme '*Pa Rak Nam Rak Pandin*' ('forest loves water, conserve the land') to raise environmental awareness in the Thai population through the dissemination of information and knowledge regarding forest conservation and watershed restoration. The main focuses include prevention of forest fires and community forest management. It follows from the above that it is recommended that actions be taken to improve environmental awareness through environmental education. The specific recommendations are given in Table 7.13.

Table 7.13 Recommended agencies and actions for promoting environmental education and awareness

Recommended agencies	Actions
Department of Environmental Quality Promotion (DEQP), Bangkok	Act as programme leader. Establish more Provincial Environmental Education Centres (PEEC) in Chiang Mai. Train educators and teachers to develop local environmental curricula.
Chiang Mai Provincial Education Office (PEO)	Include EE into its provincial action plans. Promote EE curriculum development in all schools in Chiang Mai.
Learning Centre of King Bhumibhol's Philosophy of Economic Sufficiency and Queen Sirikit Botanic Garden (QBG)	Provide EE through their environmental camps for school children.
Ministry of Education	Provide funding for the EE programme in Chiang Mai through PEO.

7.2.9 Improving the Landscape in Muang District

The objective of a tree-planting plan, as part of the project *Air Quality Management in Chiang Mai and Lamphun Provinces*, is to plant trees along the roads for a distance of 160 km and create 29 'green' spaces for recreational areas. However, it is suggested that the decision makers for the tree-planting scheme should consider that not all tree species are equally beneficial with respect to air quality. Trees can help clean the air by removing pollutants, especially O_3, NO_2 and particulates, but they can also emit volatile organic compounds (VOCs) into the atmosphere (Hewitt, 2002). Suitable tree species for reducing air pollution in Chiang Mai are: birch (family Betulaceae) and maple (family Aceraceae). Unsuitable tree species that emit air pollutants, especially VOCs that cause O_3 formation, are willows (family Salicaceae) that grow in damp areas such as by rivers (e.g. *Salix tetrasperma*, *Salix babylonica* and oak (family Fagaceae) (e.g. *Quercus kingiana; Quercus kerrii*) (Gardner *et al.*, 2000). Table 7.14 summarises the local tree species common in Chiang Mai that are potentially best able to reduce air pollution.

Table 7.14 Recommended tree species for reducing air pollution in Chiang Mai

Family	Species
Birch	
Betulaceae	*Betula alnoides*
	Betula acuminate
Maple	
Aceraceae	*Acer angustilobum*
	Acer calcaratum
	Acer chiangdaoensis
	Acer craibianum
	Acer decandrum
	Acer garretti
	Acer lanceolatum
	Acer laurinium
	Acer niveum
	Acer oblongum
	Acer philippinum
	Acer sterculiaceum
	Acer thomsonii
	Acer villosum
	Acer wilsonii

Table 7.15 Recommended agencies and actions for improving the landscape in Muang District

Recommended agencies	Actions
Chiang Mai Office of Public Works and Town and Country Planning (CMOPT)	Act as programme leader. Identify areas needed for landscape improvement (for tree planting). Design gardens or small parks to suit Chiang Mai landscape. Propose the plan including perspective views and layouts to the CEO Governor for approval and funding.
Queen Sirikit's Botanic Garden (QBG), Chiang Mai	Provide technical advice regarding suitable plant species.

7.2.10 Prioritisation of Recommendations

A number of different recommendations are proposed above for improving local air quality management (LAQM) in Chiang Mai. For this PhD programme, the time period of short-, medium- and long-term are defined as 1-3, 4-6 and 7-10 years respectively to allow the implementation of recommended measures and anticipated improvements. This depends upon the urgency of air pollution solutions and existing capacities (e.g. technical and financial) as well as current relevant national and provincial policies. A summary of recommended measures, proposed agencies (acting as programme leader), timescale and level of urgency are summarized in Table 7.17.

For example, an emissions inventory for Chiang Mai Province could be a short-term priority for AQM decision makers to identify major sources of air pollutants. It could then later be decided to implement suitable measures to reduce emissions from such sources. In addition, enforcement of laws to regulate polluting industries is needed to be undertaken urgently by the authorities (e.g. DIW and PCD) and this should be a short-term priority such legal frameworks, for the most part, already exist. For the medium-term, although the Thailand Environment Institute (TEI) and PCD have a technical capacity with respect to cleaner production, it will take time to convince industry to adopt cleaner technologies because this is not generally required by current environmental regulations, and only environmentally conscious industries are likely to apply such innovative approaches to their production processes and services.

Among the longer term recommendations, provincial policies concerning the improvement of environmental education (EE) and awareness for all schools in Chiang Mai will take longer to implement because this has to involve the Ministry of Education in including EE policies and strategic plans into the National Education Plan. Additionally, the establishment of a public transport system in Chiang Mai would likely be a long-term measure because it involves different government agencies to undertake the following actions: drafting of a plan and proposal to the Chiang Mai Governor for inclusion in a provincial plan; proposal to Central Government for approval and budget allocation; conduct an economic feasibility study (required for projects with high investment costs); purchase of LPG buses; test service, etc. Nevertheless, this measure is likely to be undertaken in some form, not only to resolve air pollution problems but also because, similar to other cities in Asia, there is an increasing demand of public transport as a consequence of population growth, urbanization and industrialization in Chiang Mai, (APMA and CAI-Asia, 2004).

Table 7.16 Recommended measures for improvement of local air quality in Chiang Mai, assigned to relevant agencies and with likely timescale.

Urgency	Recommended measures	Proposed programme leader	Timescale
High	i) Development of an emissions inventory for Chiang Mai Province	PCD	Short-term
	ii) Dissemination of air quality information	PRD3	Short-term
	iii) Control of air pollution from industrial sources	DIW	Short-term
	iv) Control of rice stalk burning	PAEO	Short- to medium-term
	v) Burning control of other agricultural wastes	Learning Centre	Short-term
	vi) Improved regulation of polluting vehicles	PCD	Short-term
Medium	vii) Improvement of air quality monitoring data	PCD	Short- to medium term
	viii) Promotion of a bicycle campaign, road safety and construction of bike lanes	CMM	Short- to medium-term
	ix) Establishment of a school bus service in Chiang Mai	CMOPT	Short- to medium-term
Low	x) Establishment of a public transport system in Chiang Mai	CMOPT	Long-term
	xi) Promotion of cleaner production for industries	PCD	Medium- to long-term
	xii) Promotion of environmental education for all schools in Chiang Mai	DEQP	Medium- to long-term
	xiii) Improvement of the landscape in Muang District	CMOPT	Long-term

7.3 Recommendations for Further Research

The following recommendations are for further research to complement those for sustainable measures to improve air quality in Chiang Mai (Table 7.17). These are not aimed directly at governmental organizations to conduct, but for researchers in general who are working or studying in universities or in non-governmental organizations. In terms of urgency, these recommendations are not considered as crucial as those, outlined in Section 7.4, that require provincial government organizations in Chiang Mai and federal departments to implement as part of their responsibilities. Therefore, time-scales such as those applied in the previous section are not suggested.

7.3.1 Atmospheric Dispersion Modelling Programmes

The findings in Chapter 2 (Modelling Air Quality in Chiang Mai) suggested that, in the application of dispersion modelling programmes to Chiang Mai conditions, a principal requirement is the capability to predict air quality when: wind speeds are very low; UV radiation levels and precipitation rates are high; the topography is complex; large area sources such as agricultural burning and forest fires are present. With this requirement in mind, atmospheric dispersion models that are likely to be more suitable to Chiang Mai conditions should be investigated and tested, or developed. Possible airshed modelling programmes (such as UAM-V, CALGRID, TAPM and Models3/CMAQ) are recommended for investigation of their suitability for application in Chiang Mai (see Section 1.5.3.1ii).

7.3.2 Health Studies

Many paediatric studies of asthma and allergies in Thailand have been conducted by medical researchers. Their major concerns have focused upon indoor factors (dust mites, cat and dog dander) and other aeroallergens such as grass (Tuchinda *et al.*, 1987; Kongpanichkul *et al.*, 1997; Vichyanond, 2002); statistics of admission of asthmatic cases (Visitsunthorn *et al.*, 1995) and ISAAC surveys (Vichyanond *et al.*, 1998; Trakultivakorn, 1999). However, these published studies did not derive clear correlations between the prevalence of asthma (and allergic diseases) and air pollutants. In Chiang Mai, there have been only a limited number of epidemiological studies carried out, therefore cross-sectional and case-control studies should be conducted, particularly of the combined effects of air pollution mixtures and their health impacts. In comparison to the study on the prevalence of respiratory diseases and allergies among school children in Chiang Mai (Chapter 4), the aspects that should be taken into consideration include: i) larger sample size; different study areas; ii) different target groups (e.g. farmers, construction workers, factory workers, traffic police, and tourists); iii) inclusion of different diseases (e.g. cardiovascular diseases, migraine). In order to conduct studies of the correlation between air pollution and mortality and morbidity, the data concerning both daily deaths and hospital admissions, and air quality should be comprehensive and accurate. Furthermore, standard guidelines concerning the statistical analysis of data should be developed for researchers so that the application of appropriate, consistent and comparable statistical methodology in epidemiological research is ensured.

7.3.3 Social Science and Communication Arts

Social science studies are needed to explore effective measures to foster and strengthen positive attitudes among government officials towards the Good Urban Governance (GUG) concept in Chiang Mai. A perception-related media behavioral study should be conducted with the aim of encouraging environmental awareness regarding air pollution. Media and events appropriate for each age group, occupation and educational level could also be developed for Chiang Mai Province (e.g. campaign of waste separation and re-cyclying, campaign to stop burning, etc.).

CHAPTER 8

REFFERENCES

AEAT Technology plc. (2001). Automatic Urban Network (AUN) Site Operation's Manual. [online]. Oxfordshire: AEA Technology plc. Available from: http://www.aeat.co.uk/netcen/airqual/reports/lsoman/head.html [Accessed 10 January 2006].

Air Pollution in the Megacities of Asia (APMA) project and the Clean Air Initiative for Asian Cities (CAI-Asia). (2004). A strategic framework for air quality management. Manila: CAI-Asia.

Airmetrics. (2001). MiniVolTM Portable Air Sampler operation manual. Oregon:Airmetrics.

Anunthavorasakul, A. (2004). Environmental Education in Thailand: Policy and Practice. [online]. Miyagi: Miyagi University of Education. Available from: www.eec.miyakyo-u.ac.jp/APEID2004/pdf/Athapol.pdf [Accessed 17 May 2006].

André, P., Bitondo, D., Berthelot, M. and Louillet, D. (2001). Development of a conceptual and methodological framework for the integrated assessment of the impacts of linear infrastructure projects on quality of life. [online]. Canadian Environmental Assessment Agency. Available from: http://www.ceaa-acee.gc.ca/015/0002/0015/3_e.htm [Accessed 20 February 2006].

Asher, M.I., Keil, U., Anderson, H.R., Beasley, R., Crane, J., Martinez, F., Mitchell, E.A., Pearce, N., Sibbald, B., Stewart, A.W., Strachan, D., Weiland, S.K., and Williams, H.C. (1995). 'International Study of Asthma and Allergies in Childhood (ISAAC): Rationale and methods'. European Respiratory Journal. 8, p.483 – 491.

Asia Travel. [Homepage of the AT Reservation Network Pte Ltd.]. [online]. 2 January 2006. Available from: http://www.asiatravel.com [Accessed 10 January 2006].

Ayers, M. (1998). 'Basic air pollution theory' in E. R.Alley (ed.) Air quality control handbook. USA: McGraw-Hill, p10-25.

Beaglehole, R., Bonita, R. and Kjellstrom, T. (1993). Basic epidemiology. Geneva: World Health Organisation.

Bergin, M., Hagler, G., Salmon, L., Zheng, M., Chameides, W., Kiang, C.S., Schmeides, W, Kiang, C.S., Schaner, J., and Yu, J. (2004). Pilot study on the use of atmospheric measurements to manage air quality in Hong Kong and the Pearl River Delta (PRD): Fine particulate matter ($PM_{2.5}$) in the PRD. HK SAR: Civic Exchange.

Bolte, G., Bishof, W., Borte, M., Lehmann, I., Wichmann, H.E. and Heinrich, J. (2003). 'Early endotoxin exposure and atopy development in infants: results of a birth cohort study'. Clinical and Experimental Allergy. 33,(6), p.770-776.

Boynton, P.M. (2004). 'Administering, analyzing, and reporting your questionnaire'. BMJ. [online]. 328. Available from: http:// bmj.bmjjournals.com [Accessed 20 February 2006].

Boynton, P.M. and Greenhalgh, T. (2004). 'Selecting, designing, and developing your questionnaire'. BMJ. [online]. 328. Available from: http:// bmj.bmjjournals.com [Accessed 20 February 2006].

Boynton, P.M., Wood, G.W. and Greenhalgh, T. (2004). 'Reaching beyond the white middle classes'. BMJ. [online]. 328. Available from: http:// bmj.bmjjournals.com [Accessed 20 February 2006].

Burks, W. (2003). 'Skin Manifestations of Food Allergy'. Pediatrics. 111, p.1617 – 1624.

Cambridge Environmental Research Consultants Ltd (CERC). (2001). ADMS-Urban User Guide version 1.6. Cambridge: CERC.

Cambridge Environmental Research Consultants Ltd (CERC). (2002). ADMS-Urban 1.6 Training Manual. Cambridge: CERC.

Cambridge Environmental Research Consultants Ltd (CERC). (2003a). ADMS-Urban User Guide version 2.0. Cambridge: CERC.

Cambridge Environmental Research Consultants Ltd (CERC). (2003b). EMIT User Guide version 2.1. Cambridge: CERC.

Carr-Hill, R. and Chalmers-Dixon, P. (2002). A review of methods for monitoring and measuring social inequality, deprivation and health inequality. [online]. York: Centre for Health Economics, University of York. Available from: http://www.ihs.ox.ac.uk/sepho/publications/carrhill/vii/7-4-2.htm [Accessed 1 March 2006].

Carruthers, D.J., Blair, J.W. and Johnson, K.L. (2002). 'Dispersion of air pollution in urban areas in the United Kingdom'. Proceedings of International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. [online]. Available from: http://www.harmo.org/Conferences/Proceedings/_Sofia/publishedSections/Pages249to253.pdf [Accessed 31 January 2005].

CH_2M Hill (China) Ltd. (2002). Study of air quality in the Pearl River Delta region. (Agreement no. CE 106/98). HK SAR: CH_2M Hill.

Chew, F.T., Goh, D.Y. and Lee, B.W. (1999). 'Geographical comparison of the prevalence of childhood asthma and allergies in Singapore'. Annals of Tropical Paediatrics. 19, p.383-390.

Chatterton, T., Dorling, S., Lovett, A. and Stephenson, M. (2000). 'Air quality in Norwich, UK multi-scale modelling to assess the significance of city, country and regional pollution sources' in R.S. Sokhi, R. San Josè, N. Moussiopoulos, and R Berkowicz (eds.). Urban air quality: measurement, modelling and management. The Netherlands: Kluwer Academic. p425 – 433.

Chiang Mai Municipality (CMM). (2002a). Air Pollution Situation in Chiang Mai. Chiang Mai: CMM.

Chiang Mai Municipality (CMM). (2002b). Summary on Building Capacity of Thai Federal and a Provincial Air Quality Department Project. Chiang Mai: CMM.

Chiang Mai Provincial Office (CMPO). (2003). Integrated strategy of development for Chiang Mai Province B.E. 2547 – 2550 (1994-1997). Chiang Mai: CMPO.

Ching, J. and Byun, D. (1999). 'Chapter 1: Introduction to the Model-3 Framework and the Community Multiscale Air Quality Model (CMAQ)' in D. Byun, and J. Ching (eds.). Science Algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ) Modelling System. Washington DC: US EPA.

Civic Exchange. (2004). Hong Kong and Pearl River Delta pilot air monitoring project: Executive summary. HK SAR: Civic Exchange.

Clean Air Initiative for Asian Cities (CAI-Asia). (2005). CAI-Asia Strategy 2005-2007. [online]. Manila: CAI-Asia. Available from: http://www.cleanairnet.org/asia/1412/article-59291.html [Accessed 25 April 2006].

Clean Air Net. [Homepage of Clean Air Initiative for Asian Cities]. [online]. January 2006. Available from: http://www.cleanairnet.org [Accessed 23 January 2006].

Commission for Integrated Transport (2001). Motorists' Forum: Air Quality. [online]. London: Crown. Available from: http://www.cfit.gov.uk/mf/reports/laq/index.htm [Accessed 20 March 2006].

Committee for Resolving Dust, Air, and Noise Pollution in Chiang Mai (CRANC). (2005). Air Pollution Abatement in Chiang Mai Province. Progress Report. Chiang Mai: CRANC.

Corporation of London. (1999). Air Quality Review Stage 3. London: Corporation of London.

Cory, C., Kurukulasuriya, L., Kiatsinsap, W., Sirisampan, V., and Sukonthapan, P. (1998). Southeast Asia handbook of selected national environmental laws. [online]. Bangkok: Chareon-Pol Press. Available from: http://www.mekonglawcenter.org/index-resource.htm [Accessed 28 April 2006].

Custovic, A., Simpson, B.M. and Simpson, A. (2001). 'Effect of environmental manipulation in pregnancy and early life on respiratory symptoms and atopy during the first year of life: a random trial'. Lancet. 358, p.188 – 193.

de la Rosa, E. (2002). 'Thailand'. In T. Banurl, A. Najun, and N. Odeh (eds.). Civic Entrepreneurship: A civil society perspective on sustainable development Volume 5 (South

East Asia Report). [online]. Pakistan: Gandhara Academy Press, p.202-257. Available from: http://www.tellus.org/seib/publications/civic/volume5.pdf [Accessed 17 May 2006].

Delphian Detection Technology (2006). Sensor Technology. [online]. New Jersey: Delphian. Available from: http://www.habmigern2003.info.suggestions/IR/Infrared-sensors.html [Accessed 10 January 2006].

Department for Environment, Food and Rural Affairs (DEFRA). (2003). Part IV of the Environment Act 1995: Local Air Quality Management. [online]. London: Crown. (LAQM.TG03). Available from: http://www.defra.gov.uk/environment/airquality/laqm/guidance/pdf/laqm_tg03.pdf [Accessed 12 April 2006].

Department for the Environment, Food and Rural Affairs (DEFRA) (2005). Air Quality Expert Group Report on Particulate Matter. [online]. London: Crown. Available from: http://www.defra.gov.uk/environment/airquality/aqeg/particulate-matter/pdf/ch5.pdf [Accessed 10 January 2006].

Department of Energy Development and Promotion (DEDP). (2000). Thailand energy situation 2000. Bangkok: DEDP.

Department of Environmental Quality Promotion (DEQP). (2006). Provincial Environmental Education Centre [online]. Bangkok: DEQP. Available from: http://www.deqp.go.th/info/info-8-1.jsp?languageID=en [Accessed 17 May 2006].

Department of Provincial Administration (DOPA). (2001). Organisation structure of the Department of Local Administration. [online]. Bangkok: DOPA. Available from: http://www.dopa.go.th/english/layout/chapter2.htm [Accessed 15 January 2006].

Derwent, R.G. (1999). 'Atmospheric chemistry' in S.T. Holgate, J.M. Samet, H.S. Koren, and R.L. Maynard (eds.) Air Pollution and Health. San Diego: Academic Press. p51-62.

Deshmukh, C.T. (2000). Asthma. [online]. Pediatirc Oncall. Available from: http://www.pediatriconcall.com/fordoctor/DiseasesandCondic=tion/asthma.asp [Accessed 23 March 2006].

DMTI Spatial. (2004). Interpolation methods for generalizing ozone concentration patterns. [online]. Ontario: DMTI Spatial. Available from: http://www.dmtispatial.com [Accessed 19 January 2006].

European Topic Centre on Air and Climate Change. (ETC/ACC) (2003). Long description of model 'ADMS-Urban'. [online]. The Netherlands: ETC/ACC. Available from: http://pandora.meng.auth.gr/mds/ [Accessed 19 January 2006].

Department of Agricultural Extension (DOAE). (2005). Introduction to DOAE, [online]. Bangkok: DOAE. Available from: http://www2.doae.go.th/introdoae/Eng_pack1.pdf [Accessed 29 May 2006].

Department of the Environment, Transport and the Regions (DETR). (1999). Source Apportionment of Airborne Particulate Matter in the United Kingdom. London: Crown.

Department for Environment, Food and Rural Affairs (DEFRA). (2000). First phase air quality review and assessment. London: DEFRA.

Department of Health (DoH). (1997). Health effects of exposures to mixtures of air pollutants (4^{th} report). London: Crown.

Department of Health (DoH). (1998). Handbook on air pollution and health. London: Crown.

Diaz-Sanchez, D., Tsien, A., Casillas, A., Dotson, A. R., Saxon, A. (1996). 'Enhanced nasal cytokine production in human beings after *in vivo* challenge with diesel exhaust particles'. Journal of Allergy and Clinical Immunology. 98, p.114 – 123.

Diaz-Sanchez, D. (1997). 'The role of diesel exhaust particles and their associated polyaromatic hydrocarbons in the induction of allergic airway diseases'. Allergy. 52 (suppl 38), p.52 – 56.

Droste, J.H.J., Wieringa, N.H., Weyler, J.J., Nelen, V.J., Vermeire, P.A., and Van Bever, H.P. (2000). 'Does the use of antibiotics in early childhood increase the risk of asthma and allergic disease?'. Clinical and Experimental Allergy. 30, p.1547 – 1553.

Enarson, D.A. (2005). 'Fostering a spirit of critical thinking: the ISAAC story'. International Journal of Tuberculosis and Lung Disease. [online]. 9(1). Available from: http://docstore.ingenta.com [Accessed 30 March 2006].

Enright, P.L., Studnicka, M. and Zielinski, J. (2005). 'Spirometry to detect and manage chronic obstructive pulmonary disease and asthma in the primary care setting'. European Respiratory Journal. [online]. 31. Available from: http:// www.viasyshealthcare.com/ prod_serv/download/ra_ch1.pdf [Accessed 23 March 2006].

Environmental Protection Department (EPD). (1993). Guidance Note for the Best Practicable Means for Cement Works (Concrete Batching Plant). [online]. Hong Kong SAR: EPD. (BPM3/2) Available from: http://www.epd.gov.hk/epd/textonly/ english/environmentinhk/air/guide_ref/files/bpm3_2.pdf [Accessed 29 May 2006].

Environmental Protection Department (EPD). (1998). Air quality in Hong Kong 1998. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/ english/environmentinhk/air/files/aqr98e.pdf [Accessed 25 April 2006].

Environmental Protection Department (EPD). (1999). Air quality in Hong Kong 1999. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/ english/environmentinhk/air/files/aqr99e.pdf [Accessed 25 April 2006].

Environmental Protection Department (EPD). (2000). Air quality in Hong Kong 2000. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/ english/environmentinhk/air/files/aqr00e.pdf [Accessed 25 April 2006].

Environmental Protection Department (EPD). (2001). Air quality in Hong Kong 2001. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/ english/environmentinhk/air/files/aqr01e.pdf [Accessed 25 April 2006].

Environmental Protection Department (EPD). (2002a). Air quality in Hong Kong 2002. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/ english/environmentinhk/air/files/aqr02e.pdf [Accessed 25 April 2006].

Environmental Protection Department (EPD). (2002b). Air quality monitoring network of Hong Kong. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/

textonly/english/environmentinhk/air/air_quality/backgdf_2.html [Accessed 25 April 2006].

Environmental Protection Department (EPD). (2003a). Air quality in Hong Kong 2003. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/english/environmentinhk/air/files/aqr03e.pdf [Accessed 25 April 2006].

Environmental Protection Department (EPD). (2003b). A guide on indoor air quality certification scheme for offices and public places. HK SAR: EPD.

Environmental Protection Department (EPD). (2003c). Guidance notes for the management of indoor air quality in offices and public places. HK SAR: EPD.

Environmental Protection Department (EPD). (2004a). Air quality objectives of Hong Kong. [online]. HK SAR: EPD. Available from: http://www.epd-asg.gov.hk/english/backgd/hkaqo.php [Accessed 28 April 2006].

Environmental Protection Department (EPD). (2004b). Environment Hong Kong 2004: Air. [online]. HK SAR: EPD. Available from: http://www.epd.gov.hk/epd/misc/ehk04/english/air/index.html [Accessed 28 April 2006].

Environmental Protection Department (EPD). (2004c). VOCs cause air pollution: A proposed scheme to require mandatory registration and labelling of the contents of volatile organic compounds in specified products. HK SAR: EPD. (Consultation document).

Environmental Protection Department (EPD). (2005). A concise guide to the ozone layer protection (controlled refrigerants) regulation. [online]. HK SAR: EPD. (Revision A1, 2005) Available from: http://www.epd.gov.hk/epd/english/environmentinhk/air/guide_ref/files/cgt_olp_cr_eng.pdf [Accessed 28 April 2006].

Environmental Protection Department (EPD). (2006a). Air Pollution Index & You. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/english/environmentinhk/air/air_quality/api_you.html [Accessed 1 May 2006].

Environmental Protection Department (EPD). (2006b). Air Pollutants and greenhouse gases. [online]. Hong Kong SAR: EPD. Available from: http://www.epd.gov.hk/epd/english/environmentinhk/air/data/emission_inve.html [Accessed 1 May 2006].

Environmental Protection Department (EPD). (2006c) Environmental education and awareness in Hong Kong. [online]. HK SAR: EPD. Available from: http://www.epd.gov.hk/epd/english/envir_education/enviredu_aware/highlights03.html [Accessed 1 May 2006].

Ernst, P. and Cormier, Y. (2000). 'Relative scarcity of asthma and atopy among rural adolescents raised on a farm'. American Journal of Respiratory and Critical Care Medicine. 161, p.1563 – 66.

EUROPA. [Homepage of the European Commission]. [online]. 1 September 2004. Available from: http://europa.eu.int [Accessed 10 January 2006].

Fabbri, L.M. and Hurd, S.S. (2003). 'Global strategy for the diagnosis of COPD in asymptomatic elderly never-smokers'. European Respiratory Journal. 20, p.1117-1122.

Field, A. (2000). Discovering statistics using SPSS for Windows: Advanced techniques for the beginner. London: Sage.

Fu, J.S., Jang, C.C., Streets, D.G. (2004). National/regional air quality modeling assessment in China using an advanced air quality modeling system. [CD-ROM]. Proceeding of 13th World Clean Air and Environmental Protection Congress and Exhibition. London.

Fusco, D., Forastiere, F., Michelozzi, P., Spadea, T., Ostro, B., and Perucci, C.A. (2001). 'Air pollution and hospital admissions for respiratory conditions in Rome, Italy'. Eur Respir J. 17, p.1143 – 1150.

Gardner, S., Sidisunthorn, P. and Anusarnsunthorn, V. (2000). A field guide to forest trees of Northern Thailand. Bangkok: Kobfai Publishing Project.

Gehring, U., Cyrys, J., Sedlmeir, G., Brunekreef, B., Bellander, T., Fischer, P., Bauer, C.P., Reinhardt, D., Wichmann, H.E. and Heinrich, J. (2002). 'Traffic-related air pollution and respiratory health during the first 2 yrs of life'. Eur Respir J. 19, p.690 – 698.

Global Initiative for Asthma (GINA). (2002). Global strategy for asthma management and prevention. Maryland: U.S. National Institutes of Health.

Guariso, G., Pirovano, G. and Volta, M. (2004). 'Multi-objective analysis of ground-level ozone concentration control'. Journal of Environmental Management. [online]. 71, (1). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Guo, H., Lee, S.C., Louie, P.K.K. and Ho, K.F. (2004). 'Characterisation of hydrocarbons, halocarbons and carbonyls in the atmosphere of Hong Kong'. Chemosphere 57, p.1367 – 1372.

Haq, G., Han, W-J., Kim, C. and Vallack, H. (2002). Benchmarking urban air quality management and practice in major and mega cities of Asia (Stage 1). [online]. Seoul: Air Pollution in Megacities of Asia (APMA). Available from: http://www.unep.org/PDF/APMA_Benchmarking_report.pdf [Accessed 25 April 2006].

Haileamlak, A., Lewis, S.A., Britton, J., Venn, A.J., Woldemariam, D., Hubbard, R., and Williams, H.C. (2005). 'Validation of International Study of Asthma and Allergies in Children (ISAAC) and UK criteria for atopic eczema in Ethiopian children'. British Journal of Dermatology. 152,(4), p.735-741.

Hanna, S. R. and Davis, J. M. (2002). 'Evaluation of a photochemical grid model using estimates of concentration probability density functions'. Atmospheric Environment. [online]. 36, (11). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Hanna, S.R., Lu, Z., Frey, H.C., Wheeler, N., Vukovich, J., Arunachalam, S., Fernau, M. and Hansen, D.A. (2001). 'Uncertainties in predicted ozone concentrations due to input uncertainties for the UAM-V photochemical grid model applied to the July 1995 OTAG domain'. Atmospheric Environment. [online]. 35, (5). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Hanna, S.R., Moore, G.E. and Fernau. M.E. (1996). 'Evaluation of photochemical grid models (UAM-IV, UAM-V, and the ROM/UAM-IV couple) using data from the lake michigan ozone study (LMOS)'. Atmospheric Environment. [online]. 30, (19). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Harashimi, Y. (2000). 'Environmental governance in selected Asian developing countries'. Environmental Review for Environmental Strategies. [online]. 1, (1). Available from: http://iges.or.jp [Accessed 28 April 2006].

Harrison, R.M. (1996). 'Air pollution: Sources, concentration and measurement' in R.M. Harrison (ed.) Pollution: Causes, effects and control. (3rd ed). London: The Royal Society of Chemistry. P.144-168.

Health Effects Institute (HEI) International Scientific Oversight Committee. (2004). Health effects of outdoor air pollution in developing countries of Asia: A Literature Review. Capital City Press: Vermont.

Heinrich, J., Hoelscher, B., Wjst, M., Cyrys, J., and Wichmann, H.E. (1999). 'Respiratory diseases and allergies in two polluted areas in East Germany'. Environ Health Perspect. 107, p.53 – 62.

Herbarth, O., Fritz, G.J., Wildfuhr, W., Behler, J.C. (1997). 'Microscaled intra-city epidemiologic risk analysis of traffic- and domestic-heating-attributed immission effects on airway disease and allergies among Children' in H. Power, T. Tirabassi, and C.A. Brebbia (eds.) Air pollution & modelling. Computational Mechanics publications. p.1023 – 1032.

Hesselmar, B., Aberg, N., Eriksson, B. and Bjorksten, B. (1999). 'Does early exposure to cat or dog protect against later allergy development?'. Clinical and Experimental Allergy. 29, p.611-617.

Hickmann, A.J. and Colwill, D.M. (1982). The Estimation of Air Pollution Concentrations from Road Traffic. Transport and Road Research Laboratory. TRRL Laboratory Report 1052. Crowthorne: Transport and Road Research Laboratory.

Hicks, R. (2005). Health: Eczema. [online]. London: British Broadcasting Corporation (BBC). Available from: http://www.bbc.co.uk/health/conditions/eczema1.shtml [Accessed 31 January 2006].

Highways Agency. (1999). Design manual for roads and bridges. London: Stationary Office.

Highways Agency. (2003). Design manual for roads and bridges. London: Stationary Office.

Hill, J.S., Patel, P.D. and Turner, J.R. (1999). Performance Characterisation of the MiniVol $PM_{2.5}$ sampler. [online]. Washington University in St Louis. Available from: http://www.airmetrics.com/downloads/1999TurnerStudy.pdf [Accessed 14 February 2006].

Hirsch, T., Weiland, S.K., von Mutius, E., Safeca, A.F., Grafe, H., Csaplovics, E., Duhme, H., Keil, U. and Leupold, W. (1999). 'Inner city air pollution and respiratory health and atopy in children'. Eur Respir J. 14, p.669 – 667.

Hopkinson, L. (2004). Particulate matter standards in Hong Kong and the Pearl River Delta Region. HK SAR: Civic Exchange.

Huang, J.P.L., Fung, J.C.H., and Lau, A.K.H. (2002). 'Study of microscale urban air dispersion by ADMS – Urban'. Proceedings of the Better Air Quality in Asian and Pacific Rim Cities Conference (BAQ 2002). Available from: http://www.cse.polyu.edu.hk/~activi/BAQ2002/BAQ2002_files/Proceedings/PosterSession/44.pdf [Accessed 31 January 2006].

Huizenga, C., Haq, G., Schwela, D., Fabian, H. and Ajero, M. (2004). Air quality management capability in Asian cities. [online]. Manila: CAI-Asia. Available from: http://www.cleanairnet.org/caiasia/142/article-59072.html [Accessed 25 April 2006].

Hurley, P., Blockley, A. and Rayner, K. (2001). 'Verification of a prognostic meteorological and air pollution model for year-long predictions in the Kwinana industrial region of Western Australia'. Atmospheric Environment. [online]. 35, (10). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Hurley, P, Manins, P., Lee, S., Boyle, R., Ng, Y.L. and Dewundege, P. (2003). 'Year-long, high-resolution, urban airshed modelling: verification of TAPM predictions of smog and particles in Melbourne, Australia'. Atmospheric Environment. [online]. 37, (14). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Hurley, P., Physick, W. and Luhar, A. (2005). 'TAPM: a practical approach to prognostic meteorological and air pollution modelling'. Environmental Modelling & Software. [online]. 20, (6). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

International Study of Asthma and Allergies in Childhood (ISAAC). (1998). 'Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC'. Lancet. 351, (9111), p.1225 – 1232.

Houtkoop-Steenstra, H. (2000). Interaction and the standardized survey interview: the living questionnaire. Cambridge: Cambridge University Press.

Hunter, P.R., Bickerstaff and Davies, M.A. (2004). 'Potential sources of bias in the use of individual's recall of the frequency of exposure to air pollution for use in exposure assessment in epidemiological studies: a cross-sectional survey'. Environmental Health: A Global Access Science Source. [online]. 3,(3). Available from: http:// biomedcentral.com [Accessed 1 March 2006].

Jacob, D.J. (2000). The oxidizing power of the atmosphere. [online]. Havard University. Available from: http://www-as.harvard.edu/chemistry/trop/publications/jacob2000/ text.html [Accessed 14 February 2006].

Japan International Cooperation Agency (JICA). (2002). Study on Improvement of Road Traffic Environment in Chiang Mai City: Interim report 2. Bangkok: JICA.

Jarrett, D. (2004). Research methods: The importance of design. London: Middlesex University.

Jean, A., Zock, J., Kogevinas, M., Ferrer, A. and Marin, A. (2006). 'Occupation, smoking, and chronic obstructive respiratory disorders: a cross sectional study in an industrial area of Catalonia, Spain'. Environmental Health: A Global Access Science Source. [online]. 5,(2). Available from: http:// biomedcentral.com [Accessed 1 March 2006].

Jiang, G., Lamb, B. and Westberg, H. (2003). 'Using back trajectories and process analysis to investigate photochemical ozone production in the Puget Sound region'. Atmospheric Environment. [online]. 37, (11). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Jiang, W., Singleton, D.L., Hedley, M. and McLaren, (1997). R. 'Sensitivity of ozone concentrations to VOC and NO_x emissions in the Canadian Lower Fraser Valley'. Atmospheric Environment. [online]. 31, (4). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Juniper, E.F., Howland, W.C., Roberts, N.B., Thompson, A.K. and King, D.R. (1998). 'Measuring quality of life in children with rhiniconjunctivitis'. Journal of Allergy and Clinical Immunology. 101 (2 Pt 1), p.163-70.

Juniper, E.F., Goyatt, G.H., Feeny, D.H., Ferrie, P.J., Griffith, L.F., and Townsend, M. (1996). 'Measuring quality of life in children with asthma'. Quality of Life Research. 5, p.35-36.

Kilpelainen, M., Terho, E.O., Helenius, H., Koskenvuo, M. (2000). 'Farm environment in childhood prevents the development of allergies'. Clinical and Experimental Allergy. 30,(2), p.135-137.

Kolehmainen, M., Martikainen, H., Hiltunen, T., and Ruuskanen, J. (2000). 'Forecasting Air Quality Parameters Using Hybrid Neutral Network Modelling' in R.S. Sokhi, R. San José, N. Moussiopoulos and R. Berkowicz (eds.). Urban air quality: Measurement, modelling and management. The Netherlands: Kluwer Academic, p.277 – 286.

Kongpanichkul, A., Vichyanond, P., and Tuchinda, M. (1997). 'Allergen skin test reactivities among asthmatic Thai children. Journal of Medical Association of Thailand. [online]. 80, (2). Available from: www.ncbi.nlm.nih.gov [Accessed 29 April 2006].

Koutrakis, P. and Sioutas, C. 1996. 'Physico-chemical properties and measurement of ambient particles' in R. Wilson and J. Spengler (eds.) Particles in our air: Concentration and health Effects. Boston, MA. Harvard University Press p15-40.

Kim, J.Y., Song, C.H., Ghim, Y.S., Won, J.G., Yoon, S.C., Carmichael, G.R. and Woo, J.-H. (in press). 'An investigation on NH_3 emissions and particulate NH_4^+–NO_3^- formation in East Asia' Atmospheric Environment. [online]. Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Kramer, U., Lemmen, C.H., Behrendt, H., Link, E., Schafer, T., Gostomzyk, J., Schere, G., and Ring, J. (2004). 'The effect of environmental tobacco smoke on eczema and allergic sensitization in children'. British Journal of Dermatology. 150,(1), p.111-118.

Krailerg, N. (2004). 'Business news: Now garbage is more than just a load of rubbish'. Chiang Mai Mail. [online]. 25 May. Available from: http://www.chiangmai-mail.com/082/business.html. [Accessed 15 June 2005].

Kulig, M., Bergmann, R. and Klettke, U. (1999). 'Natural course of sensitization to food and inhalant allergens during the first 6 years of life'. Journal of Allergy and Clinical Immunology. 103, p.1173-1179.

Le Tertre, A., Quenel, P., Eilstein, D., Medina, S., Prouvost, H., Pascal, L., Boumghar, A., Saviuc, P., Zeghnoun, A., Filluel, L., Declercg, C., Cassadou, S., Le Goaster, C. (2002). 'Short-term Effects of Air Pollution on Mortality in nine French Cities: a Quantitative Summary'. Arch Environ Health. [online]. 57, (4). Available from: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12530597&dopt=Abstract [Accessed 30 January 2006].

Leuzzi, G. (2002). 'A Sensitivity Analysis of ADMS-Urban'. Proceedings of International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. [online]. Available from: http://www.harmo.org/Conferences/Proceedings/_Sofia/publishedSections/Pages328to332.pdf [Accessed 31 January 2005].

Liao, D., Creason, J., Shy, C., Williams, R., Watts, R. and Zweidinger, R. (1999). 'Daily variation of particulate air pollution and poor cardiac autonomic control in the elderly'. Environ Health Perspect. 107, p.521 – 525.

Lindfors, A., van Hage-Hamsten, M., Rietz, H., Wickman, M. and Nordvall, S.L. (1999). 'Influence of interaction of environmental risk factors and sensitization in young asthmatic children'. Journal of Allergy and Clinical Immunology. 104, p.755-762.

Louie, P.K.K., Chow, J. C., Chen, L.W.A., Watson, J., Leung, G., and Sin, D.W.M. (2005). '$PM_{2.5}$ Chemical composition in Hong Kong: urban and regional variations'. Science of Total Environment. 338, (3), p.267-281.

Martinez, F.D. 2001. 'The coming-of-age of the hygiene hypothesis'. Respiratory Research. 2, p.129-132.

MARC/UNEP/WHO. (1996). Air quality management and assessment capabilities in 20 major cities. Nairobi: UNEP. (UNEP/DEIA/AR.96.2/WHO/EOS.95.7).

Mari Mari. (2004). Geography of Hong Kong. [online]. Available from: http://www.marimari.com/content/hong_kong/general_info/geography/main/html [Accessed 28 April 2006].

Matza, L.S., Swensen, A.R., Flood, E.M., Secnik, K. and Leidy, N.K. (2004). 'Assessment of health-related quality of life in Children: A review of conceptual, methodological and regulatory issues'. Value in Health. [online]. 7(1). Available from: http://blackwell-synergy.com [Accessed 23 March 2006].

Maupin, A.J. (2003). Quality assurance project plan for the State of Idaho ambient air quality monitoring program. [online]. Idaho: Department of Environmental Quality. Available from: http://www.deq.idaho.gov/air/data_reports/monitoring/qapp_0603_text.pdf [Accessed 10 January 2006].

McCandless, R.R., Oliva, G. (2002). Guidelines for statistical analysis of public health data with attention to small numbers. Family Health Outcomes Project at the University of California: San Francisco.

McDonnell, W.F., Nishino-Ishikawa, N., Petersen, F.F., chen, L.H., and Abbey, D.E. (2000). 'Relationships of mortality with the fine and coarse fractions of long-term ambient PM_{10} concentrations in nonsmokers'. J Expos Anal Environ Epidemiol. 10, p.427 – 436.

McHugh, C., Sheng, X., and Carruthers, D. (2005). Using ADMS models for air quality assessment and management in China. [online]. Cambridge:CERC. Available from: http://www.cerc.co.uk/software/pubs/Using%20ADMS%20models%20in%20China.pdf [Accessed 31 January 2005].

MedicineNet. [online]. 2 January 2006. Available from: http://www.medterms.com [Accessed 19 January 2006].

Medisave. [Homepage of Medisave UK Ltd.]. [online]. 10 March 2006. Available from: http://www.medisave.co.uk [Accessed 30 March 2006].

Melen, E., Wickman, M. and Nordvall, S.L. (2001). 'Influence of early and current environmental exposure factors on sensitisation and outcome of asthma in pre-school children'. Allergy. 56, p.646-652.

Merkus, P.J.F.M., de Jongste, J.C. and Stocks, J. (2005). 'Respiratory function measurements in infants and children'. European Respiratory Journal. [online]. 31. Available from: http:// www.viasyshealthcare.com/prod_serv/download/ra_ch9.pdf [Accessed 23 March 2006].

Montnemery, P., Nihlén, U, Löfdahl, C. G., Nyberg, P. and Svensson, Å. (2003). 'Prevalence of self-reported eczema in relation to living environment, socio-economic status and respiratory symptoms assessed in a questionnaire study'. BMC Dermatology. [online]. 3,(4). Available from: http://www.pubmedcentral.nih.gov [Accessed 30 March 2006].

Moore, M. (2005). A study of air pollution on the Archway Road (A1), London. BPhil, Middlesex University (UK), School of Health and Social Sciences.

Morris, A. (2005). Allergic rhinitis. [online]. London: British Broadcasting Corporation (BBC). Available from: http://www.bbc.co.uk/health/conditions/eczema1.shtml. [Accessed 31 January 2006].

Mortimer, K.M., Neas, L.M., Dockery, D.W., Redline, S., and Tager, I.B. (2002). 'The effect of air pollution on inner-city children with asthma'. Eur Respir J. 19, p.699 – 705.

Mortimer, K.M., Neas, L.M., Dockery, D.W., Redline, S., and Tager, I.B. (2002). 'The effect of air pollution on inner-city children with asthma'. European Respiratory Journal. 19, p.699-705.

Mortimer, K., Tager, I., Dockery, D., Neas, L., and Redline, S. (2000). 'The effects of ozone on inner-city children with asthma'. American Journal of Respiratory and Critical Care Medicine. 162,(5), p.1838-1845.

Murray, F. (1997). 'Urban Air Pollution and Health Effects'. in: D. Brune, D.V. Chapman, M.D. Gwynne, and J.M. Pacyna (eds.). The Global Environment. Germany: Scandinavian Science Publisher, p585-598.

Mutebi, A. M. (2005). 'Government and Citizen Engagement at the Local Level in Thailand: Nan Municipality's Roundtables and Expert Panels'. Asia Pacific: Perspectives. 5, (2), p.16-28.

National Academy of Science (1983). Acid deposition: Atmospheric process in Eastern North America. [online]. Washington D.C.: National Academy Press. Available from: http://www.fermat.nap.edu/catalog/182.html [Accessed 14 February 2006].

National Economic and Social Development Board (NESDB). (2001). Summary of the Ninth National Economic and Social Development Plan (2002 – 2006). Bangkok: Kurusapa Business Organization.

National Health Service (NHS). (2005). Health Encyclopaedia. [online]. London: NHS. Available from: http://www.nhsdirect.nhs.uk/alphaindex.asp [Accessed 31 January 2006].

National Institute of Water and Atmospheric Research (2004). Good Practice Guide for Atmospheric Dispersion Modelling. [online]. Wellington: Department for the Environment. (ME 522) Available from: http://www.mfe.govt.nz/publications/air/atmospheric-dispersion-modelling-jun04/ [Accessed 10 January 2006].

Newson, R.B., Shaheen, S.O., Chinn, S. and Burney, P.G. (2000). 'Paracetamol sales and atopic disease in children and adults: an ecological analysis'. European Respiratory Journal. 16, p.817-23.

Nualvatna, K. (2003). 'Country paper: Thailand'. In R. Oliver (ed.). Development of Agribusiness Enterprises. [online]. Tokyo: Asian Productivity Organization (APO), p166-174. Available from: http://www.apo-tokyo.org/00e-books/AG-09_DevAgriBusiness/17.Nualvatna.DevAgEnt.pdf [Accessed 29 May 2005]

Numed Cardiac Diagnostics. [Homepage of Numed Holdings Ltd.]. [online]. 30 January 2006. Avalable from: http://www.numed.co.uk [Accessed 30 March 2006].

Office of the Commission for the Management of Road Traffic (OCMRT). (2002). Project on traffic and transport planning in Chiang Mai. Bangkok: Thailand.

Office of Natural Resources and Environmental Policy and Planning (ONEP). (1997a). Thailand State of the Environment Report: Executive summary. [online]. Bangkok: ONEP. Available from: http://www.onep.go.th/eng/soe1997_1.asp [Accessed 28 May 2006].

Office of Natural Resources and Environmental Policy and Planning (ONEP). (1997b). Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality 1997-2016. Bangkok: ONEP. Available from: http://www.onep.go.th/eng/policy_1.asp [Accessed 17 May 2006].

Office of Natural Resources and Environmental Policy and Planning (ONEP). (2002). Thailand State of Environment 2002: Executive summary. [online]. Bangkok: ONEP. Available from: http://www.onep.go.th/eng/soe2002_ex.pdf [Accessed 17 May 2006].

Office of the National Education Commission (ONEC). (2002). Education in Thailand. [online]. Bangkok: ONEC. Available from: http://www.onec.go.th/publication/education03/fulledu02-03.pdf [Accessed 17 May 2006].

Office of the Permanent Secretary of Natural Resources and Environment (OPS). (2004). Getting to Know the Ministry of Natural Resources and Environment. Bangkok: OPS.

Oglesby, L., Kunzli, N., Monn, C., Shindler, C., Ackermann-Liebrich, U. and Leuenberger, P. (2000). 'Validity and annoyance scores for estimation of long term air pollution exposure in epidemiological study: the Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA). American Journal of Epidemiology. 152, p. 75-83.

Oh, I., Kim, Y., Lee, H. and Kim, C. (2006). 'An observational and numerical study of the effects of the late sea breeze on ozone distributions in the Busan metropolitan area, Korea'. Atmospheric Environment. [online]. 40, (7). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Oppenheim, A.N. (1992). Questionnaire design, interviewing and attitude measurement. London: Continuum.

Ostro, B.D., Eskeland, G.S., Sanshez, J.M. and Feyzioglu, T. (1999). 'Air Pollution and Health Effects: A Study of Medical Visits among Children in Santiago, Chile'. Environ Health Perspect. 107, p.69 – 73.

Ownby, D.R., Johnson, C.C., and Peterson, E.P. (2002). 'Exposure to dogs and cats in the first year of life and risk of allergic sensitization at 6 to 7 years of age'. Journal of the American Medical Association. 228,(8), p.963 – 972.

Owen, B., Edmunds, H.A., Carruthers, D.J., Singles, R.J. (2000). 'Prediction of total oxides of nitrogen and nitrogen dioxide concentrations in a large urban area using a new generation urban scale dispersion model with integral chemical model'. Atmospheric Environment. 34, p.397-406.

Peat, J., Mellis, C., Williams, K. and Xuan W. (2002). Health Science Research: A Handbook of Quantitative Methods. London: Sage.

Phankingthongkum, S., Daengsuwan, T., Visitsunthorn, N., Thamlikitkul, V., Udompunthuruk, S. and Vichyanond, P. (2002). 'How do Thai children and adolescents describe asthma symptoms?'. Pediatric Allergy and Immunology. [online]. 13 (2). Available from: http://blackwell-synergy.com [Accessed 23 March 2006].

Pilinis, C., Kassomenos, P. and Kallos, G. (1993). 'Modeling of photochemical pollution in Athens, Greece'. Application of the RAMS-CALGRID modeling system'. Atmospheric Environment. [online]. 27, (4). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Poachanukoon, O., Visitsunthorn, N., Leurmarnkul, W. and Vichyanond, P. (2005). 'Pediatric asthma quality of life questionnaire (PAQLQ): Validation among asthmatic children in Thailand'. Pediatric Allergy and Immunology. [online]. Available from: http://blackwell-synergy.com [Accessed 23 March 2006].

Poboon, C. (2004). The Environment Fund: Financial Mechanism in Domestic Wastewater Management in Thailand. [online]. Asian Institute of Technology. Available from: http://www.serd.ait.ac.th/uem/sea-uema/snp/tp1/ChenisaThailandtext.pdf [Accessed 10 January 2006].

Pollution Control Department (PCD). (1994a). Air and Noise Emission Database for Thailand. Bangkok: PCD.

Pollution Control Department (PCD). (1994b). Study on Establishment of Industrial Air Emission Standards. Bangkok: Quality and Safety Center.

Pollution Control Department (PCD). (1997a). Laws and Standards on Pollution Control in Thailand. (4th ed). Bangkok: PCD.

Pollution Control Department (PCD). (1997b). The Pollution Prevention and Mitigation Policy (1997-2016). [online]. Bangkok: PCD. Available from: http://www.pcd.go.th/info_serv/en_reg_polair.html [Accessed 17 May 2006].

Pollution Control Department (PCD). (1999). State and management of air and noise pollution. Bangkok: PCD.

Pollution Control Department (PCD). (2000a). State and management of air and noise pollution. Bangkok: PCD.

Pollution Control Department (PCD). (2000b). Air emission source database update and ambient air quality impact assessment in Bangkok Metropolitan Region. Bangkok: SECOT.

Pollution Control Department (PCD). (2002). Emission inventory plan for Chiang Mai Municipality. Bangkok: PCD.

Pollution Control Department (PCD). (2003). State and management of air and noise pollution. Bangkok: PCD.

Pollution Control Department (PCD). (2004a). State and Management of Air and Noise Pollution. Bangkok: PCD.

Pollution Control Department (PCD). (2004b). A partnership for sustainable air quality improvement in Bangkok. [online]. Bangkok: PCD. Available from: http:// www.pcd.go.th/info_serv/air_diesel.html [Accessed 28 April 2006].

Pollution Control Department. (2004c). Developing Integrated Emission Strategy for Existing Land Transport (DIESEL) Programme (Status report). [online]. Bangkok: PCD. Available from: http://infofile.pcd.go.th/air/DIESEL_Progress_Mar04.pdf [Accessed 29 May 2006].

Pollution Control Department (PCD). (2005). State of Air Quality and Noise Pollution. [online]. Bangkok: PCD. Available from: http://infofile.pcd.go.th/mgt/ pollution2547_3air_en.pdf [Accessed 17 May 2006].

Pope III, C.A., Hill, R.W. and Villegas, G.M. (1999). 'Particulate Air Pollution and daily Mortality on Utah's Wasatch Front'. Environ Health Perspect. 107, p.567 – 573.

Popp, W., Rauscher, H., Sertl, K., Wanke, T. and Zwick, H. (1990). 'Risk factors for sensitization to furred pets'. Allergy. 45, p.75 – 79.

Pothikamjorn, S.L., Ruxrungtham, K., Thampanitchawong, P., Fuangthong, R., Srasuebkul, P., Sangahsapaviriyah, A., Suttithavil, W., Klaewsongkram, J., Parisuthikul, V., Viravan, T., Rumsaeng, V., Kana, K., Direkwattanachai, C., Kamchaisathien, V. and Phanupak, P. (2002). 'Impact of particulate air pollutants on allergic diseases, allergic skin reactivity and lung function'. Asian Pacific Journal of Allergy and Immunology. 20, p.77-83.

Pride, N.B. (2000). 'Tests of forced expiration and inspiration'. in: J.M.B. Hughes and N.B. Pride (eds.). Lung function tests: Physiological principles and clinical applications. London: WB Saunders. p.3-26.

Purvis, D.J., Thompson, J.M.D., Clark, P.M., Robinson, E., Black, P.N., Wild, C.J. and Mitchell, E.A. (2005). 'Risk factors for atopic dermatitis in New Zealand children at 3-5 years of age'. British Journal of Dermatology. 152,(4),p.742-749.

Riedler, J., Eder, W., Oberfeld, G. and Schreuer, M. (2000). 'Austrian children living on a farm have less hay fever, asthma and allergic sensitization'. Clinical and Experimental Allergy. 30, p.194-200.

Rogerson, R.J. (1997). Quality of Life in Britain. Glasgow: Quality of Life Research Group, University of Strathclyde.

Romagnani, S. (1992). 'Human Thl and Th2 subsets: Regulation of differentiation and role in protection and immunopathology'. International Archives of Allergy and Immunology. 98, p.272-285.

Roost, H.P., Kunzli, N., Schindler, C., Jarvis, D., Chinn, S., Perruchoud, A.P., Ackermann-Liebrich, U., Burney, P. and Wuthrich, B. (1999). 'Role of current and childhood exposure to cat and atopic sensitization: European community respiratory health survey'. Journal of Allergy and Clinical Immunology. 104, p.941-947.

Ropkins, K. and Colvile, R.N. (2000). Critical review of air quality monitoring technologies for Urban Traffic Management and Control (UTMC) systems. [online]. London: Department for Transport. Available from: http://www.utmc.gov.uk/utmc28/pdf/utmc28-rp1.pdf [Accessed 10 January 2006].

Royal Thai Government. (1999). The Economic Aspects of Sustainable Development in Thailand. [online]. Bangkok: the United Nations. Available from: http://www.un.org/esa/agenda21/natlinfo/countr/thai/eco.htm#indus [Accessed 10 January 2006].

Ruppel, G. (1994). Manual of pulmonary function testing. (6th ed). St. Louis: Mosby-Year Book.

Sakurai, T., Fujita, S., Hayami, H. and Furuhashi, N. (2003). 'A case study of high ammonia concentration in the nighttime by means of modeling analysis in the Kanto region of Japan'. Atmospheric Environment. [online]. 37, (31). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

San José, R., Pedraza, L.D., Salas, I., and González, R.M. (2000). 'The impact of road traffic in Madrid community by using a nested Gaussian Mesoscale Air Quality Model

(GAMA)'. in R.S. Sokhi, R. San José, N. Moussiopoulos and R. Berkowicz (eds.). Urban air quality: Measurement, modelling and management. Kluwer Academic. The Netherlands, p.469 – 476.

Sangchan, W. (2005). Determination of polycyclic aromatic hydrocarbons in particulate matter in Chiang Mai City. MSc, Chiang Mai University (Thailand), Graduate School.

Sapsford, R. (1999). Survey research. London: Sage.

Schäfer, T. and Ring, J. 1997. 'Epidemiology of allergic diseases'. Allergy. Suppl 38, p.14-22.

Schalock, R.L. (2004). 'The concept of Quality of Life: what we know and do not know'. Journal of Intellectual Disability Research. [online]. 48, (3). Available from: http://bmj.bmjjournals.com [Accessed 20 February 2006].

Schwartz, J. (2001). 'Is There Harvesting in the Association of Airborne Particles with daily Deaths and Hospital Admission?'. Epidemiology. 12, p.55 – 61.

Seatec International Ltd. (1995). Thailand Sewerage Prioritization Project. Bangkok: Seatec International Ltd.

Shutes, R.B.E. (2002). Air Pollution and Health: Respiratory and Circulatory Diseases: Airing Your View meeting document. London: Middlesex University.

Shytov, A. (2005). 'Public participation in environmental protection and Thai folk wisdom'. Online Thailand Law Journal. [online]. 8, (2). Available from: http://thailawforum.com [Accessed 28 April 2006].

Sicklick, M.J. (2005). Breastfeeding, allergies and asthma. [online]. Allergy Health Online. Available from: http://allergy.healthcentersonline.com/childrenallergyasthma/breastfeedingallergiesasthma.cfm [Accessed 30 March 2006].

Simachaya, W. and Runghirunviroj, S. (2001). 'Environmentally sound technologies in water quality management in Thailand'. in United Nations Environment Programme

(UNEP). Transfer and implementation of environmentally sound technologies for water quality management in the Mekong River Basin. Bangkok: UNEP, p.51-60.

Simpson, R., Denison, L., Petroeschevsky, A., Thalib, L., and Williams, G. (2000). 'Effects of Ambient Particle Pollution on Daily Mortality in Melbourne, 1991 – 1996'. J Exposure Analysis and Environ Epidemio. 10, p.488 – 496.

Snidvongs, K. (1993). 'The economic and political issues in the development of environment, science and technology'. Asian Society for Environmental Protection. 9, (1), p.1-3,10.

Sopchokchai, O. (2001). Good local governance and anti-corruption through people's participation: A case of Thailand. [online]. Bangkok: The Office of Civil Service Commission. Available from: http://www1.worldbank.org/publicsector/decentralization/ TAO-e1.doc [Accessed 17 May 2006].

Special Interest Research Group on Quality of Life. (2000). Quality of Life: Its conceptualisation, measurement and application. [online]. The International Association for the Scientific Study of Intellectual Disabilities. Available from: http://www.beachcenter.org/Books/5cFullPublications%5cPDF%5cFQLI-Quality%20of%20Life %20Concensus%20Document.pdf [Accessed 20 February 2006].

Sreshthaputra, N. and Indaratana, K. (2001). The universal coverage policy of Thailand: An introduction. [online]. Asia Pacific Health Economics Network. Available from: http:// http://www.unescap.org/aphen/thailand_universal_coverage.htm [Accessed 20 February 2006].

Stewart, A. 2002. Basic Statistics and Epidemiology: A Practical Guide. London: TJ International.

Streets, D. G., Chang, Y. -S., Tompkins, M. Ghim, Y. S. and Carter. L. D. (2001). 'Efficient regional ozone control strategies for the eastern United States'. Journal of Environmental Management. [online]. 61, (4). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Takafuji, S., Suzuki, S., Muranaka, M. and Miyamoto, T. (1989). 'Influence of environmental factors on IgE production'. Ciba Foundation Symposium. 147, p.188-201.

Tam, A.Y.C., Wong, C.M., Lam, T.H., Ong, S.G., Peters, J. and Hedley, A.J. (1994). 'Bronchial responsiveness in children exposed to atmospheric pollution in Hong Kong'. Chest. 106, p.1056-1060.

Team Consulting Engineers Co. Ltd. (1997). Development of guideline for selection and application of mathematical models for assessment of impact on water quality, air quality and noise pollution from industrial projects. Bangkok: Team Consulting Engineers Co. Ltd.

Teledyne Technologies Incorporated (1997). Instruction manual for Model 300 carbon monoxide analyzer. [online]. Califonia: Teledyne. Available from: http://teledyne-api.com/manuals/02163G.M300.Manual.pdf [Accessed 10 January 2006].

Thailand Environment Institute. (2003). A Development of Natural Resources and Environmental Management Model for Local Administrative Organisation: Executive Summary. Bangkok: Office of the Natural Resources and Environmental Policy and Planning (OEPP).

Thailand Environment Institute (TEI). (2005). Annual report 2004. [online]. Bangkok: TEI. Available from: http://www.tei.or.th/AboutTEI/pdf/AR2004.pdf [Accessed 29 May 2006].

The Government of Hong Kong SAR. (1997). Laws of Hong Kong: Air Pollution Control Ordinance (Chapter 311). [online]. HK SAR: The Government of HK SAR. Available from: http://www.justice.gov.hk/ [Accessed 28 April 2006].

Tienboon, P. and Wahlqvist, M. (1996). 'Children, AIDS and Nutrition: an Experience from Chiang Mai, Thailand'. Asia Pacific Journal of Clinical Nutrition. 5, p.84-87.

Towse, A., Mills, A. and Tangcharoensathien, V. (2004). 'Learning from Thailand's health reform'. BMJ. [online]. 328. Available from: http:// bmj.bmjjournals.com [Accessed 20 February 2006].

Trakultivakorn, M. (1999). 'Prevalence of asthma, rhinitis and eczema in Northern Thai children from Chiang Mai (International Study of Asthma and Allergies in Childhood, ISAAC)'. Asian Pacific Journal of Allergy and Immunology.17, p.243-248.

Tuchinda, M., Habananada, S., Vareenil, J., Srimaruta, N., and Piromrat, K. (1987). 'Asthma in Thai children: a study of 2000 cases'. Annals of Allergy. [online]. 59, (3). Available from: www.ncbi.nlm.nih.gov [Accessed 29 April 2006].

United States Environmental Protection Agency (US EPA). (1999). Determination of PM10 in Ambient Air Using the Thermo Environmental Instruments (Formerly Wedding&Associates) Continuous Beta Attenuated Monitor. [online]. Ohio: US EPA. (Compendium Method IO-1.2). Available from: http://www.epa.gov/ttn/amtic/files/ambient/inorganic/mthd-1-2.pdf [Accessed 10 January 2006].

United Nations Development Programme (UNDP). (1997). Governance for sustainable human development. New York: UNDP.

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). (2002). What is good governance?. [online]. Bangkok: United Nations Development Programme (UNDP). Available from: http://www.unescap.org/huset/gg/governance.htm [Accessed 25 April 2006].

United Nations Educational, Scientific, and Cultural Organization (UNESCO). (2000). Education For All 2000: Thailand Country Reports. [online]. Bangkok: UNESCO. Available from: http://www2.unesco.org/wef/countryreports/thailand/contents.html [Accessed 17 May 2006].

United Nations Environment Programme (UNEP). (2001). Cleaner Production: Key elements. [online]. Available from: http://www.uneptie.org/pc/cp/understanding_cp/home.htm#definition [Accessed 29 May 2006].

United Nations Human Settlements Programme (UN-HABITAT). (2002). The global campaign on urban governance: Concept paper. [online]. (2nd ed). Nairobi: UN-HABITAT. Available from: http://www.unchs.org/campaigns/governance/documents/governing_our_cities_env_and_urb.pdf [Accessed 25 April 2006].

University Corporation for Atmospheric Research (UCAR). (2006). Atmospheric Numerical Model. [online]. Pennsylvania: Pennsylvania State University/National Centre for Atmospheric Research. Available from http://box.mmm.ucar.edu/mm5 [Accessed 1 March 2006].

Uwanno, B. and Burns, W. D. (1998). 'The Thai Constitution of 1997: Sources and process'. University of British Columbia Law Review. [online]. 32, (2). Available from: http://thailawforum.com [Accessed 28 April 2006].

van Teijlingen, E.R. and Hundley, V. (2001). The importance of pilot studies. [online]. Surrey: University of Surrey. Available from http://www.soc.surrey.ac.uk/sru/sru35.html [Accessed 1 March 2006].

von Ehrenstein, O.S., von Mutius, E., Illi, S., Baumann, L., Bohm, O., and von Kries, R. (2000). 'Reduced risk of hay fever and asthma among children of farmers'. Clinical and Expimental Allergy. 30, p.187-193.

Ventura, S.J., Martin, J.A., Curtin, S.C., Mathews, T.J., Park, M.M. (2000). 'Births: Final Data for 1998'. in: National Center for Health Statistics. National Statistics Reports. Maryland: National Center for Health Statistics. 48(3), p.95.

Vichyanond, P. (2002). 'Pediatric allergy and immunology at Siriraj Hospital'. Journal of Medical Association of Thailand. [online]. 85, (Suppl 2). Available from: www.ncbi.nlm.nih.gov [Accessed 29 April 2006].

Vichyanond, P., Jirapongsananuruk, O., Visitsuntorn, N., and Tuchinda, M. (1998). 'Prevalence of asthma, rhinitis and eczema in children from Bangkok area using the ISAAC (International Study of Asthma and Allergies in Childhood) questionnaires'. Journal of Medical Association of Thailand. 81:175 – 84.

Villasenor, R., Claiborn, C., Lamb, B. and O'Neill, S. (2001). 'Mesoscale modeling of wintertime particulate matter episodes in eastern Washington, USA'. Atmospheric Environment. [online]. 35, (36). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Visitsunthorn, N., Sittichockananon, N., Tuchinda, M. and Wongsinchao, S. (1995). 'A comparison of admission patterns of childhood asthma in 1982 and 1992'. Asian Pacific Journal of Allergy and Immunology. 13,(2), p.123-128.

Wahn, U. and von Mutius, E. (2001). 'Childhood Risks Factors for Atopy and the Importance of Early Intervention'. Journal of Allergy and Clinical Immunology. 107, p.567-574.

Waiyawajamai, S. (2003). Statistics of factories operating in Chiang Mai Province. [online]. Chiang Mai: Industry Office. Available from: http:e.chiangmai.go.th/45manase/ view-detail45.php?tid=625 [Accessed 14 February 2006].

Wangwongwatana, S. and Warapetcharayut, P. (2001a). Air pollution management in Thailand. [online]. Air Pollution in Megacities of Asia (APMA). Available from: http://www.asiairnet.org/publications/11-Thailand.pdf. [Accessed 7 February 2004].

Wangwongwatana, S. and Warapetcharayut, P. (2001b). A summary of capacity building project for central and local government officials in improving air and noise quality in Chiang Mai Municipality. Bangkok: Pollution Control Department (PCD).

Wark, K., Warner, C.F., and Davis, W.T. (1998). Air pollution: Its origin and control. (3rd ed). Menlo Park: Addison-Wesley.

Walsh, B. (2004). 'Choking on growth'. Time. 13 December, 164,(24) 16-24.

Wedding, J.B. and Weigland, M.A. (1991). Wedding&Associates PM10 (or TSP) Beta Gauge Automated Particle Sampler Operations and Maintenance Manual. Colorado: Fort Collins.

Westfall, M.S. and de Villa, V.A. (2001). Asian Development Bank (ADB) Cities Data Book: Urban indicators for managing cities. [online]. Manila: ADB. Available from: http://www.adb.org/Documents/Books/Cities_Data_Book/06chapter6.pdf [Accessed 1 May 2006].

White, A. (2003). Taking on tobacco smoke pollution around the world!. [online]. Washington D.C.: Global Partnerships for Tobacco Control. Available from: http://lists.essential.org/pipermail/gptc/2003q1/000017.html [Accessed 4 April 2006].

Wikipedia. [The Wikimedia Foundation, Inc.]. [online]. 1 March 2006. Available from: http://www.en.wikipedia.org [Accessed 10 March 2006].

Williams, M.L. (1996). 'Atmospheric dispersal of pollutants and the modelling of air pollution'. in R.M. Harrison (ed.). Pollution: Causes, effects and control. (3rd ed). London: The Royal Society of Chemistry, p.221 – 240.

Wilson, J.G. and Zawar-Reza, P. (2006). 'Intraurban-scale dispersion modelling of particulate matter concentrations: Applications for exposure estimates in cohort studies'. Atmospheric Environment. [online]. 40, (60). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Wiwatanadate, P. and Chunram, N. (2002). Health Impacts of Air Quality in Chiang Mai: Interim Report for EC Asia Urbs project. Chiang Mai: Chiang Mai University.

Wong, C.M., McGhee, S.M., Yeung, R.Y.T., Thach, T.Q., Wong, T.W. and Hedley, A.J. (2002). Study of short-term impact and costs due to traffic-related air pollution. HK SAR: University of Hong Kong.

Wongsurakiat, P., Maranetra, K.N., Nana, A., Naruman, C., Aksornint, M., Chalermsanyakorn, T. (1999). 'Respiratory symptoms and pulmonary function of traffic policemen in Thonburi'. Journal of Medical Association of Thailand. 82, p.435-443.

World Health Organization. (1996). Introduction, administration, scoring and generic version of the assessment. [online]. Geneva: World Health Organization. (WHOQOL-BREF). Available from: http://www.who.int/mental_health/media/en/76.pdf [Accessed 1 March 2006].

World Health Organisation (WHO). (2002). The World Health Report. Geneva: WHO.

Yang, C-Y, Wang, J-D, Chan, C-C, Chen, P-C., Huang, J-S and Cheng, M-F. (1998). 'Respiratory symptoms of primary school children living in a petrochemical polluted area in Taiwan'. Pediatric Pulmonology. 25, p.299-303.

Yeo, M.J. and Kim, Y.P. (2004). Effects of regional SO_2 emission change on the deposition of sulphur in northern Asia. [CD-ROM]. Abstracts and Full Papers: 13th World Clean Air and Environmental Protection Congress and Exhibition.

Youngsuksathaporn, P. (2005). Innovation in Thai Government. [online]. Bangkok: national Innovation Agency. Available from: http://www.nia.or.th/nis/download/ Innovation_in_Thai_Government.pdf [Accessed 17 May 2006].

Zawar-Reza, P., Kingham, S. and Pearce, J. (2005). 'Evaluation of a year-long dispersion modelling of PM_{10} using the mesoscale model TAPM for Christchurch, New Zealand'. Science of The Total Environment. [online]. 349, (1-3). Available from: http://www.sciencedirect.com [Accessed 1 February 2006].

Zhang, J., Song, H., Tong, S., Li, L., Liu, B. and Wang, L. (2000). 'Ambient sulphate concentration and chronic disease mortality in Beijing'. Science of the Total Environment. 262, p.63-71.

APPENDICES

CD – ROM

DIRECTORY OF CD-ROM

Appendix	Folder name	Sub-folder name	File name	File type
1	-	-	A1 MU Ethics approval.pdf	PDF
2	-	-	A2 Thailand Energy Consumption.doc	Word Document
3	-	-	A3 Municipal&SAO functions.doc	Word Document
4	Meteorological data	-	metdata2001.txt met1dfeb.txt met1daug.txt metaug1.txt metfeb1.txt	Text Document Text Document Text Document Text Document Text Document
	Source data	Sources (Phase 1)	input sources.wmf	Image
		Sources (Phase 2)	allareas.xls allpoints.xls allroads.xls train1.xls cm road data 2001 3.xls time varying emissions factors.xls area & point sources emissions factors.xls	Excel Spreadsheet Excel Spreadsheet Excel Spreadsheet Excel Spreadsheet Excel Spreadsheet Excel Spreadsheet Excel Spreadsheet
		Sources (Phase 3)	aug30-04orc.mdb	Microsoft Access Application
		August sources	feb20m.mdb	Microsoft Access Application
		February sources	exaug30-04.mdb	Microsoft Access Application
		Grid sources	exfeb20.mdb	Microsoft Access Application
5	-	-	A5 PM10 sampling.doc	Word Document
6	-	-	A6 QoL questionnaire.doc	Word Document
7	-	-	A7 Barnet questionnaire.doc	Word Document
8	-	-	A8 ISAAC questionnaire.doc	Word Document
9	-	-	A9 95% CI Poisson Factors.doc	Word Document